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Complete List of Authors:	Lin, Qingmin; Shanghai Jiao Tong University, School of Life Science and Biotechnology Abbey, Cody; Stanford University, Freeman Spogli Institute for International Studies Zhang, Yunting; Shanghai Childrens Medical Center Affiliated to Shanghai Jiaotong University School of Medicine, Child Health Advocacy Institute Wang, Guanghai; Shanghai Childrens Medical Center Affiliated to Shanghai Jiaotong University School of Medicine Lu, Jinkui; Shangrao Normal University, Department of Physical Education Dill, Sarah-Eve; Stanford University, Freeman Spogli Institute for International Studies Jiang, Qi; Stanford University, Freeman Spogli Institute for International Studies Singh, M.K.; Stanford University School of Medicine She, Xinshu; Stanford University School of Medicine Wang, Huan; Stanford University, Stanford Center on China's Economy and Institutions Rozelle, Scott; Stanford University, Freeman Spogli Institute for International Studies Jiang, Fan; Shanghai Childrens Medical Center Affiliated to Shanghai Jiaotong University School of Medicine, Department of Developmental and Behavioral Pediatrics
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Association between Mental Health Symptom and Executive Dysfunction in Urban-Rural Adolescents

Qingmin Lin[1], Cody Abbey[2], Yunting Zhang[3], Guanghai Wang[4,5], Jinkui Lu[6], Sarah-Eve Dill[2], Qi Jiang[2], Manpreet Kaur Singh[7], Xinshu She[7], Huan Wang[8], Scott Rozelle[2], and Fan Jiang[4,5,#]

Affiliations:

[1]School of Life Science and Biotechnology, Shanghai Jiao Tong University, Shanghai 200240, China.

[2]Freeman Spogli Institute for International Studies, Stanford University, Stanford, CA, USA.

[3]Child Health Advocacy Institute, Shanghai Children's Medical Center, School of Medicine, Shanghai Jiao Tong University, Shanghai 200127, China.

[4]Department of Developmental and Behavioral Pediatrics, Pediatric Translational Medicine Institution, Shanghai Children's Medical Center, School of Medicine, Shanghai Jiao Tong University, Shanghai 200127, China.

[5]Ministry of Education-Shanghai Key Laboratory of Children's Environmental Health, Xinhua Hospital, School of Medicine, Shanghai Jiao Tong University, Shanghai 200092, China.

[6]Department of Physical Education, Shangrao Normal University, Shangrao 334001, China.

[7]Stanford University School of Medicine, Stanford, CA, USA.

[8]Stanford Center on China's Economy and Institutions, Stanford University, Stanford, CA, USA.

[#]Corresponding author:

Fan Jiang, Department of Developmental and Behavioral Pediatrics, Pediatric Translational Medicine Institution, Shanghai Children's Medical Center, School of Medicine, Shanghai Jiao Tong University, 1678 Dongfang Rd. Shanghai 200127, China. Tel: 86-21-38626012; Fax: 86-21-58706129; Email: fanjiang@shsmu.edu.cn.

Abstract

Objectives To examine the association between mental health and executive function in general adolescents, and to identify whether home residence and school location would moderate that association.

Design A population-based cross-sectional study.

Setting 16 sampled schools in Shangrao city located in downstream Yangtze River in southeast China (December 2018).

Participants 1895 adolescents (48.8% male) which were divided into three subpopulations: a.) adolescents who have urban *hukou* (i.e., household registration in China) and attend urban schools (UU, n = 292); b.) adolescents who have rural *hukou* and attend urban schools (RU, n = 819); and c.) adolescents who have rural *hukou* and attend rural schools (RR, n = 784).

Measures The Depression Anxiety and Stress Scale-21 was used to assess adolescent mental health symptoms, and the Behavior Rating Inventory of Executive Function was applied to measure adolescent executive function in nature setting.

Results Mental health symptoms were common (depression: 25.2%, anxiety: 53.0%, stress: 19.7%) in our sample, and prevalence rates were lower among UU adolescents than among the RR and RU, with inter-subgroup differences in screen exposure time explaining most of the variance. We found the three types of symptoms were strongly associated with executive function in general adolescents. We also observed a marginal moderating effect of urban-rural subgroup on the associations: UU adolescents with

depression (OR = 6.74, 95% CI: 3.75-12.12) and anxiety (OR = 5.56, 95% CI: 1.86-16.66) had a higher executive dysfunction risk when compared to RR youths with depression (OR = 1.93, 95% CI: 0.91-4.12) and anxiety (OR = 1.80, 95% CI: 1.39-2.33), respectively.

Conclusions Rural adolescents experienced more mental health symptoms, whereas urban individuals with mental health problems had a higher executive dysfunction risk.

Keywords: adolescents, mental health, executive function, urban-rural subpopulation

Article Summary

The association between mental health symptoms and executive dysfunction in general adolescent is unclear. It is also not yet understood whether urban-rural school and residence location moderates that association. We found that the risks of depression and anxiety problems on executive dysfunction were much higher among urban adolescents when compared with rural peers, though rural adolescents experienced more depression, anxiety and stress symptoms.

Strengths and limitations of this study

1. This is a population-based cross-sectional survey using multi-stage cluster random sampling method.
2. This study investigated the moderating effect of urban-rural subpopulation on the association between mental health symptom and executive dysfunction among general adolescents.
3. The data was collected from one relatively low socioeconomic development city in China, and the findings might not be generalizable to the national population.
4. The study utilized sub-clinical cutoffs of executive dysfunction, and the measures of lifestyle behaviors were based on self-report.
5. This is a cross-sectional study, we cannot make causal claims and cannot exclude the possibility that the results may be influenced by residual and unmeasured or unknown factors.

Introduction

Mental health disorders are the leading cause of global disability burden among youth, and approximately 21% of adolescents are at risk of some kind of mental disorders such as depression and anxiety.[1] One potential consequence of poor mental health is impairment to executive functions (EFs),[2] which refer to a collection of top-down mental processes against one's bottom-up automatic actions (including three core subcomponents: inhibitory control, working memory, and cognitive flexibility) that are necessary to make decisions and engage in purposeful, goal-driven, and future-oriented behaviors.[3] Executive dysfunction (EDF), also known as EF impairment, can negatively impact physical health (e.g., obesity, overeating, poor treatment adherence),[4,5] result in antisocial behavior (e.g., aggression, violence, and criminality),[6,7] and hinder academic and career success (e.g., poor school readiness and work productivity).[8]

While mental health illnesses can increase the risk of EDF, existing studies have been predominantly focused on clinical patients, such as those suffering from major depressive disorder,[9] and few studies were conducted among general adolescents. Nowadays, more and more adolescents are troubled with mental health problems, a significant percentage of which, however, are sub-clinical symptoms (i.e., those not meeting clinical diagnostic criteria). Given that sub-clinical symptoms of a psychological illness still meaningfully may increase EF impairment, it is crucial to explore whether mental health symptoms can increase EDF among general adolescents at a population level.

The link between mental health issues and EF in general adolescents was investigated by some studies. One community study recently indicated that depressive status as measured by an epidemiological screening scale was associated with lower cognitive

flexibility and selective attention.[10] However, another population-based study including adolescents from both urban and rural areas did not find a significant association.[11] One potential reason for these differences may be that certain social factors, such as adolescent living and study environments, may moderate that link, as the distribution of economic, healthcare, and educational resources,[12,13] as well as some lifestyle behaviors (e.g., physical activity, and screen exposure),[14,15] can vary significantly based on an adolescent's home residence or school location, particularly in developing nations with large urban-rural socioeconomic disparities.[16]

Urban regions typically receive a disproportionately larger share of economic investment and have higher quality of healthcare and educational environments than rural regions, which may mitigate the presence or reduce the impact of their mental health symptoms. Meanwhile, urban regions also have a number of stressors including dense population, as well as traffic and air pollution,[17,18] which may aggravate the mental health and EF relationship. In some contexts, rural adolescents relocating to urban areas with or without their parents (migrant) tend to have worse lifestyle behaviors such as more screen exposure time,[15] and may also face a unique set of adverse circumstances such as social stigma threat from peers,[19] which may in turn impact their mental health and EF. In light of these disparities, it is possible that the association between mental health symptoms and EDF may differ by adolescent home residence and school location, yet no studies have examined their moderating effects on that association in general sample.

China is one of the most populous developing countries and has a large number of adolescent students that belong to all three of these subpopulation categories (i.e., local urban, local rural, and rural-urban migrant), which gave us a unique opportunity to investigate the association between mental health symptoms and EDF across different

urban-rural subgroups. Specifically, in China, a household registration system (i.e., *hukou*) established officially in 1958 classifies each Chinese citizen as either urban or rural origin according to his/her permanent residential area.[19] By taking into account adolescent *hukou* and school location, we can define three subgroups: a.) adolescents who have urban *hukou* and attend urban schools (UU); b.) adolescents who have rural *hukou* and attend urban schools (RU); and c.) adolescents who have rural *hukou* and attend rural schools (RR). Therefore, using a population-based Chinese sample, we aimed to measure whether or not the associations between three common mental health symptoms (i.e., depression, anxiety, and stress) and EDF among general adolescents vary across different urban-rural subpopulations.

Methods

Participants

Participants were part of the Study of the Shanghai Children's Health, Education, and Lifestyle Evaluation-Adolescents (SCHEDULE-A), which is a population-based cross-sectional survey investigating risk factors of the physical and mental health of general adolescents. The present study was conducted in Shangrao (December 2018), a relatively socioeconomically underdeveloped city located in downstream Yangtze River in southeast China. The multi-stage cluster random sampling method we used were reported in **Method S**. Briefly, based on the per capita disposable income of Chinese residents in 2016, four districts/counties were selected (**Table S1**), and four schools (two lower secondary and two upper secondary) stratified by rural and urban areas were randomly chosen from each district/county, then one class from each grade in the sampled 16 schools was randomly selected, and finally all students in the selected classes were invited to participate in the survey. Ethical approval was granted by the

Shanghai Children's Medical Center Human Ethics Committee (SCMCIRB-K2018103). We obtained written informed consent from all parents and adolescents.

Main variables

Urban-rural subgroups

We obtained the *hukou* information through parent report and school location data by referring to the official administrative urban-rural designations, and then divided the final sample into three major subpopulations (**Figure 1**): UU (n = 292), RU (n = 819) and RR (n = 784). Due to a small number of adolescents who had urban *hukou* and attended rural schools (n = 14), we did not include them in the current analysis.

Mental health symptoms

The Depression Anxiety and Stress Scale-21 (DASS-21) that has been validated among the Chinese student population was used to measure three common mental health conditions (i.e., depression, anxiety, and stress).[20] Each domain has seven items for which adolescents indicated how often they experienced the described symptom in the last week on a 4-point scale from 0 "does not apply to me at all" to 3 "applies to me very much or most of the time." The score for each domain was summed and multiplied by 2, and adolescents who scored "moderate to extremely severe" by cutoffs of ≥ 14, ≥ 10, and ≥ 19 were classified as having potential depression, anxiety, and stress conditions, respectively.

Executive dysfunction

The Behavior Rating Inventory of Executive Function (BRIEF) was used to assess adolescent EF performance,[21] which has demonstrated an acceptable reliability and validity among Chinese youth.[22] Unlike the traditional task-based testing conducted by a well trained professional within a highly structured laboratory, the BRIEF, a questionnaire-based measurement, was designed to capture an individual's everyday

behavioral and emotional aspects of EF in nature environment, and is a reliable and practical tool used in a large epidemiological study. In the current study, we used the parent report form with 86 items, and for each item, parents were asked to rate their adolescents' specific behaviors in the past six months using a 3-point scale (i.e., never, sometimes, and often). We checked the raw data based on two validity indexes (i.e., negativity < 5 and inconsistency < 7) to reduce reporting bias according to the BRIEF manual. We calculated the overall raw score (i.e., global executive composite) by adding up the following eight index scores: inhibit, emotional control, shift, initiate, working memory, plan/organize, organization of materials, and monitor. T-scores were computed based on sex- and age-specific norms, and we defined T-scores > 60 and > 65 as potentially sub-clinical and clinical EDF, respectively.

Covariates

Parents or other primary caregivers reported sociodemographic information, including parental education level, gross family income, as well as the adolescent's age, sex, and chronic disease history. Adolescents were asked to report their lifestyle behaviors. Screen exposure time was measured by two widely used questions: in the last month, on average, the total time he/she spent per day on (1) sitting and watching television or videos, and (2) playing games using device such as cellphone, iPAD, PlayStation, etc.[23] Each response was then dichotomized, with exposure time above 2 hours/day indicating excessive passive and interactive screen time, respectively. The average night sleep duration was calculated by a weighted formula (5*weekdays+2*weekends)/7 based on responses to the questions "At what time do you usually go to bed and get up on weekdays and weekends, respectively?" We defined shorter sleepers as students whose average night sleep duration was less than 9, 8, and 7 hours for students aged 12-13, 14-17 and ≥ 18 years, respectively.[24] Physical activity was examined using the short

Chinese version of the International Physical Activity Questionnaire (IPAQ), and then categorized into low, moderate, and high levels.[25]

Statistical analysis

Participant characteristics stratified by the three urban-rural subgroups were presented by means (SD) and frequencies (%), and their differences across the subgroups were tested by ANOVA (or Kruskal-Wallis) and chi-squared test for continuous and categorical variables, respectively.

To achieve our objective, we first explored risk factors of mental health symptoms and executive dysfunction using a logistic model with cluster-robust standard error. The potential risk factors were urban-rural subgroup, sociodemographic characteristics (i.e., age, sex, parental education level, and gross family income), and individual behaviors (screen time, night sleep duration, and physical activity). Second, we measured the association of urban-rural subgroup and mental health symptoms with sub-clinical EDF (due to a low prevalence of clinical EDF, see **Table 1**). Third, we examined the moderating effect of urban-rural subgroup on the relationship of mental health symptoms and EDF (i.e., adding an interactive term in each model, such as RR*depression). Finally, we determined the simple effect of the association between mental health symptoms and EDF stratified by urban-rural subgroup. Furthermore, we also performed a multiple imputation using chained equations with 20 imputed datasets and 10 burn-ins for each dataset to estimate the missing values. To test whether substantial differences existed due to imputation, we compared the results before and after the data imputation.

All data analyses were performed with Stata 15.0, and $P < 0.05$ with two-sided was set as statistical significance.

Patient and public involvement

Patients or the public were not involved in the design, conduct, reporting or dissemination plans of this study.

Results

Sociodemographic and behavioral characteristics

Overall, of the final 1,895 adolescents, the mean age was 15.33 ± 1.76 years, and 925 (48.8%) were male. Additionally, 72.9% of adolescents' parents obtained lower education levels than high school, and 58.7% of their family income was lower than 50,000 RMB. Moreover, 44.1% and 37.8% participants had excessive passive and interactive screen time, respectively; 52.5% were shorter night sleepers; and 28.9% displayed low physical activity. There were significant sociodemographic and behavioral differences across the three urban-rural subgroups (except for sex). Specifically, the RR adolescents were younger and more likely to have parents with lower education levels and family income. Furthermore, excessive screen time was more prevalent among the RU and RR adolescents, whereas short night sleep duration and less high physical activity were more common among the UU youths (**Table 1**).

Prevalence and risk factors of mental health symptoms

Overall, the prevalence of the three types of mental health symptoms was 25.2%, 53.0%, and 19.7% for depression, anxiety, and stress, respectively. There were significant differences across the three urban-rural subgroups, i.e., depression (UU, RU, and RR rates: 20.2%, 25.0%, and 27.3%; Chi-square = 5.70; P = 0.058), anxiety (41.1%, 52.1%, and 58.3%; Chi-square = 25.67; P < 0.001), and stress (14.4%, 20.5%, and 20.9%; Chi-square = 6.28; P = 0.043) (**Table 1**).

However, after adjusting for confounders, all significant differences disappeared (**Table S2**). We further conducted a post-hoc analysis by adjusting factors step by step and found that the RR adolescents had a higher risk of depression, the RR and RU had

a higher risk of anxiety, and the RR adolescents had a higher risk of stress, which were mainly due to more screen time. Additionally, the higher anxiety among RR and RU students was partly attributed to lower family income and parental education (**Table S3**).

Associations between mental health symptoms and executive dysfunction

After adjusting for confounders, all three types of mental health symptoms were significantly associated with EDF, with ORs being 3.22 (95% CI: 1.38-7.52), 2.68 (95% CI: 1.62-4.44), and 1.72 (95% CI: 1.07-2.75) for depression, anxiety, and stress, respectively (**Table 2**).

Moderating effect of urban-rural subgroup

Although we did not find a significant association between urban-rural subgroup and EDF (**Table S2**), we observed a marginal interactive effect of RR group and depression (P = 0.089) as well as RR group and anxiety (P = 0.084) on EDF (**Figure 2**, **Table S4**). In further simple analysis, we showed that the UU adolescents with depression (OR = 6.74, 95% CI: 3.75-12.12) and anxiety (OR = 5.56, 95% CI: 1.86-16.66) had a much higher risk of EDF than RR adolescents with depression (OR = 1.93, 95% CI: 0.91-4.12) and anxiety (OR = 1.80, 95% CI: 1.39-2.33) (**Table 3, Table S5)**. We also compared the results of complete-case and multiple-imputation analysis, and no much changes were found (**Table S6-S8**).

Discussion

To our knowledge, this is the first study to investigate the moderating effect of urban-rural subpopulation on the association between mental health symptom and EDF among general adolescents. We found that mental health symptoms were common in our sample, and their prevalence rates in the RR and RU subgroups were significantly higher than those in the UU subgroup, mainly due to having more screen time.

Furthermore, we observed that mental health symptoms were significantly associated with EDF across all subgroups. Moreover, there were also marginal interactive effects of urban-rural subgroup with depression and anxiety on EDF, specifically the UU adolescents with depression and anxiety issues had a much higher EDF risk than their RR peers.

Mental health symptoms were common in our sample, i.e., 25.4%, 52.8% and 19.6% for depression, anxiety, and stress, respectively, which appear to be higher than rates among Hong Kong adolescents (19.1%, 22.9%, and 14.3%).[26] Meanwhile, the mean score of the depression dimension in our dataset (8.5) was higher than that reported among adolescents in Spain (6.0),[27] about the same as that of a study conducted in Australia (8.4),[28] but less than scores reported in America (10.4).[29] The mean anxiety score (10.8) was also higher than that of a study conducted in Australia (7.0).[28]

Our finding that RR and RU adolescents had worse mental health symptoms than their UU peers was in line with prior studies conducted in China[30] and in other countries (e.g., Korea[31] and Australia[32]). Certain sociodemographic and behavioral differences between the urban-rural subgroups explained most of the disparities, which corresponded with the results of a previous study.[33] Our study indicated that the significant urban-rural differences of adolescent mental health problems were mainly attributed to screen time, which previous researches have linked to less face-to-face communication with peers and families, less outdoor physical activity, and receiving plenty of potentially inappropriate information.[34] Another possible reason for these differences may be that the lower parental education levels and family income among rural adolescents lead to less mental health support.[35] On all accounts, the large share of rural adolescents experiencing more mental health problems is concerning and

should receive more attention from policymakers, because the government policies have the potential to change many of these determinants.

Across all three subgroups in our sample, mental health symptoms were consistently associated with EDF. That is, poor mental health associated with EF impairment even among general adolescents, supporting one recent study with nonclinical-based samples.[10] Studies from clinical patients indicated that the potential mechanism may be attributed to the dysregulation of the hypothalamic–pituitary axis with hyper activity[36] and neural-immune crosstalk with elevated cytokine production[37]. When these occurred in the central nervous system, brain architecture, morphology, and functional activity may be altered, thereby reducing an adolescent's EF.[2,38] More studies on the mechanisms behind the association between mental health and EF in general adolescents should be conducted in the future.

Although we only found a marginal interactive effect of urban-rural subgroup with depression and anxiety, we observed that among adolescents with depression and anxiety symptoms, the UU adolescents had a much higher EDF risk than RR counterparts. While urban regions offer a higher standard of living and a higher quality of healthcare and educational resources than rural areas, stressors in urban environments, such as high population density, noise pollution, and air pollution, in addition to less access to green spaces and relatively low neighbor communication and support,[17,18,39,40] might strengthen the relationship between mental health problems and EDF, which is also an important topic in need of further empirical study. To improve adolescent mental health and EF, we suggest that the government and community should pay much more attention to both investment in mental health support services in rural areas as well as improving the quality of the living environment in urban areas.

The present study has several limitations. Firstly, our data was collected from one relatively low socioeconomic development city in China, and the findings might not be generalizable to the national population. Future samples in other settings with different levels of socioeconomic development should be collected. Secondly, we utilized sub-clinical cutoffs of EDF. Although the effect estimated was at magnitudes that may be considered sub-clinical in adolescents, these findings are important at the population level. Thirdly, our measures of lifestyle behaviors were based on self-report, which may be subject to recall bias. Future studies should collect these data using more objective measurements, such as using actiwatch to assess night sleep duration and physical activity. Finally, as this is a cross-sectional study, we cannot make causal claims and cannot exclude the possibility that the results may be influenced by residual and unmeasured or unknown factors.

Conclusion

The prevalence of mental health symptoms was significantly higher among rural origin adolescents when compared to their urban peers, and such disparities were primarily explained by excessive screen exposure. Adolescents with mental health symptoms were more likely to have EDF regardless of urban-rural, and urban adolescents with depression and anxiety had a much higher EDF risk than their rural peers. The results indicate the need to improve mental health issues prevention and treatment in both urban and rural areas, where adolescents may be exposed to different kinds of risk factors that may exacerbate the impact of mental health problems on their EF in daily life.

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Contributors

Qingmin Lin conceptualized and designed the study, carried out the literature review and data analyses, and critically reviewed and revised the manuscript. Cody Abbey carried out the literature review and drafted the initial manuscript. Yunting Zhang, Guanghai Wang, Jinkui Lu, Sarah-Eve Dill, Qi Jiang, Manpreet Kaur Singh, Xinshu She, Huan Wang, and Scott Rozelle critically reviewed and revised the manuscript. Fan Jiang conceptualized and designed the study, as well as critically reviewed and revised the manuscript. All authors read and approved the final manuscript.

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Conflict of interest

The authors declared no conflicts of interest.

Patient consent for publication

Not applicable.

Ethics approval

The study was approved by the Shanghai Children's Medical Center Human Ethics Committee (SCMCIRB-K2018103).

Provenance and peer review

Not commissioned; externally peer reviewed

Data availability statement

Data used for this study were derived from the SCHEDULE-A project. The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

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Figure title

Figure 1 Flowchart of the participants

Figure 2 Interactive effects of urban-rural subgroup and mental health symptoms on executive dysfunction

Table 1 Participant characteristics stratified by urban-rural subgroup

	Total (n = 1895)	Urban-rural subgroup				
		UU (n = 292)	RU (n = 819)	RR (n = 784)	Chi-square	P value
Sociodemographics						
Age, y	15.33 ± 1.76	15.53 ± 1.62	15.56 ± 1.69	15.02 ± 1.83	46.86	**< 0.001**
Sex					1.03	0.598
Boys	925 (48.8)	144 (49.3)	409 (49.9)	372 (47.5)		
Girls	970 (51.2)	148 (50.7)	410 (50.1)	412 (52.6)		
Parental education level					268.24	**< 0.001**
Lower than high school	1338 (72.9)	118 (41.0)	606 (76.6)	614 (81.1)		
High school or higher	498 (27.1)	170 (59.0)	185 (23.4)	143 (18.9)		
Gross family income (RMB)					79.39	**< 0.001**
< 50,000	921 (58.7)	95 (38.6)	397 (56.7)	429 (69.0)		
≥ 50,000	647 (41.3)	151 (61.4)	303 (43.3)	193 (31.0)		
Individual behaviors						
Screen time						
Passive screen time, ≥ 2h	836 (44.1)	65 (22.3)	335 (40.9)	436 (55.7)	102.49	**< 0.001**
Interactive screen time, ≥ 2h	715 (37.8)	41 (14.0)	259 (31.6)	415 (53.0)	160.43	**< 0.001**
Night sleep duration, short	984 (52.5)	207 (70.9)	490 (60.1)	287 (37.3)	129.62	**< 0.001**
Physical activity					22.01	**< 0.001**
Low	547 (28.9)	85 (29.1)	222 (27.1)	240 (30.7)		
Moderate	709 (37.5)	136 (46.6)	315 (38.5)	258 (33.0)		
High	637 (33.7)	71 (24.3)	282 (34.4)	284 (36.3)		
Mental health symptoms[1]						
Depression, mean score	8.48 ± 8.10	7.42 ± 7.94[a]	8.14 ± 8.05[ab]	9.22 ± 8.15[c]	19.99	**< 0.001**
≥ 14	478 (25.2)	59 (20.2)	205 (25.0)	214 (27.3)	5.70	0.058
Anxiety, mean score	10.78 ± 7.91	8.70 ± 7.20[a]	10.58 ± 8.05[b]	11.76 ± 7.86[c]	36.68	**< 0.001**
≥ 10	1004 (53.0)	120 (41.1)	427 (52.1)	457 (58.3)	25.67	**< 0.001**
Stress, mean score	12.40 ± 8.30	11.07 ± 8.03[a]	12.45 ± 8.76[b]	12.83 ± 7.85[b]	11.86	**0.003**
≥ 19	374 (19.7)	42 (14.4)	168 (20.5)	164 (20.9)	6.28	**0.043**
Executive dysfunction[1]						
Global Executive Composite, mean score	50.77 ± 10.19	50.80 ± 9.86[ab]	49.81 ± 10.42[a]	51.78 ± 9.97[b]	15.44	**< 0.001**
Sub-clinical, > 60	400 (21.1)	54 (18.5)	162 (19.8)	184 (23.5)	4.69	0.096
Clinical, > 65	180 (9.5)	23 (7.9)	88 (10.7)	69 (8.8)	2.82	0.245

RR, rural hukou and rural school group; RU, rural hukou and urban school group; UU, urban hukou and urban school group.

[1] Multiple-comparison across the three urban-rural subgroups was conducted using non-parametric independent sample median tests. Columns with the same letters are not significantly different (P ≥0.05).

Table 2 Associations between mental health symptoms and executive dysfunction

	Executive dysfunction					
	Model a Unadjusted	Model a Adjusted[1]	Model b Unadjusted	Model b Adjusted[1]	Model c Unadjusted	Model c Adjusted[1]
Mental health symptoms						
Depression, score ≥ 14	**3.29 (2.6, 4.15)*** **	**3.22 (1.38, 7.52)** **	/	/	/	/
Anxiety, score ≥ 10	/	/	**2.88 (2.26, 3.67)*** **	**2.68 (1.62, 4.44)*** **	/	/
Stress, score ≥ 19	/	/	/	/	**1.80 (1.39, 2.32)*** **	**1.72 (1.07, 2.75)***
Urban-rural subgroup						
UU	/	Ref.	/	Ref.	/	Ref.
RU	/	0.72 (0.49, 1.05)	/	**0.70 (0.50, 0.98)***	/	0.74 (0.46, 1.17)
RR	/	0.78 (0.34, 1.79)	/	0.74 (0.34, 1.58)	/	0.78 (0.35, 1.76)
Sociodemographics						
Age, y	/	0.95 (0.81, 1.10)	/	0.95 (0.80, 1.11)	/	0.95 (0.82, 1.10)
Sex, female	/	0.95 (0.75, 1.20)	/	0.90 (0.67, 1.22)	/	0.95 (0.75, 1.21)
Parental education, ≥ high school	/	**0.64 (0.51, 0.79)*** **	/	**0.69 (0.57, 0.85)*** **	/	**0.66 (0.53, 0.81)*** **
Family income, ≥ 50,000 RMB	/	**0.62 (0.40, 0.95)***	/	**0.63 (0.39, 1.00)***	/	**0.61 (0.38, 0.99)***
Individual behaviors						
Screen time						
Passive screen time, ≥ 2h	/	1.06 (0.77, 1.44)	/	1.12 (0.79, 1.58)	/	1.15 (0.76, 1.74)
Interactive screen time, ≥ 2h	/	**1.41 (1.24, 1.61)*** **	/	**1.27 (1.11, 1.45)*** **	/	**1.41 (1.26, 1.58)*** **
Night sleep duration, short	/	**0.75 (0.58, 0.97)***	/	**0.71 (0.54, 0.95)***	/	**0.74 (0.57, 0.95)***
Physical activity						
Low	/	Ref.	/	Ref.	/	Ref.
Moderate	/	0.85 (0.50, 1.45)	/	0.83 (0.55, 1.26)	/	0.83 (0.55, 1.26)
High	/	0.86 (0.53, 1.40)	/	0.90 (0.57, 1.44)	/	0.88 (0.54, 1.42)

RR, rural hukou and rural school group; RU, rural hukou and urban school group; UU, urban hukou and urban school group.

[1] Adjusted for sociodemographic characteristics (i.e., age, sex, parental education level, and gross family income) and individual behaviors (screen time, night sleep duration, and physical activity).

*P <0.05, **P<0.01, ***P <0.001.

Table 3 Simple effects of mental health symptoms on executive dysfunction stratified by urban-rural subgroup[1]

	Executive dysfunction		
	OR (95% CI)	*z* value	P value
UU group			
Depression, score ≥ 14	6.74 (3.75, 12.12)	6.38	**< 0.001**
Anxiety, score ≥ 10	5.56 (1.86, 16.66)	3.06	**0.002**
Stress, score ≥ 19	3.14 (1.75, 5.61)	3.85	**< 0.001**
RU group			
Depression, score ≥ 14	4.89 (1.67, 14.25)	2.90	**0.004**
Anxiety, score ≥ 10	3.46 (1.21, 9.84)	2.32	**0.020**
Stress, score ≥ 19	1.65 (0.92, 2.93)	1.69	0.091
RR group			
Depression, score ≥ 14	1.93 (0.91, 4.12)	1.70	0.088
Anxiety, score ≥ 10	1.80 (1.39, 2.33)	4.44	**< 0.001**
Stress, score ≥ 19	1.59 (1.12, 2.27)	2.57	**0.010**

RR, rural hukou and rural school group; RU, rural hukou and urban school group; UU, urban hukou and urban school group.

[1] Adjusted for sociodemographic characteristics (i.e., age, sex, parental education level, and gross family income) and individual behaviors (screen time, night sleep duration, and physical activity).

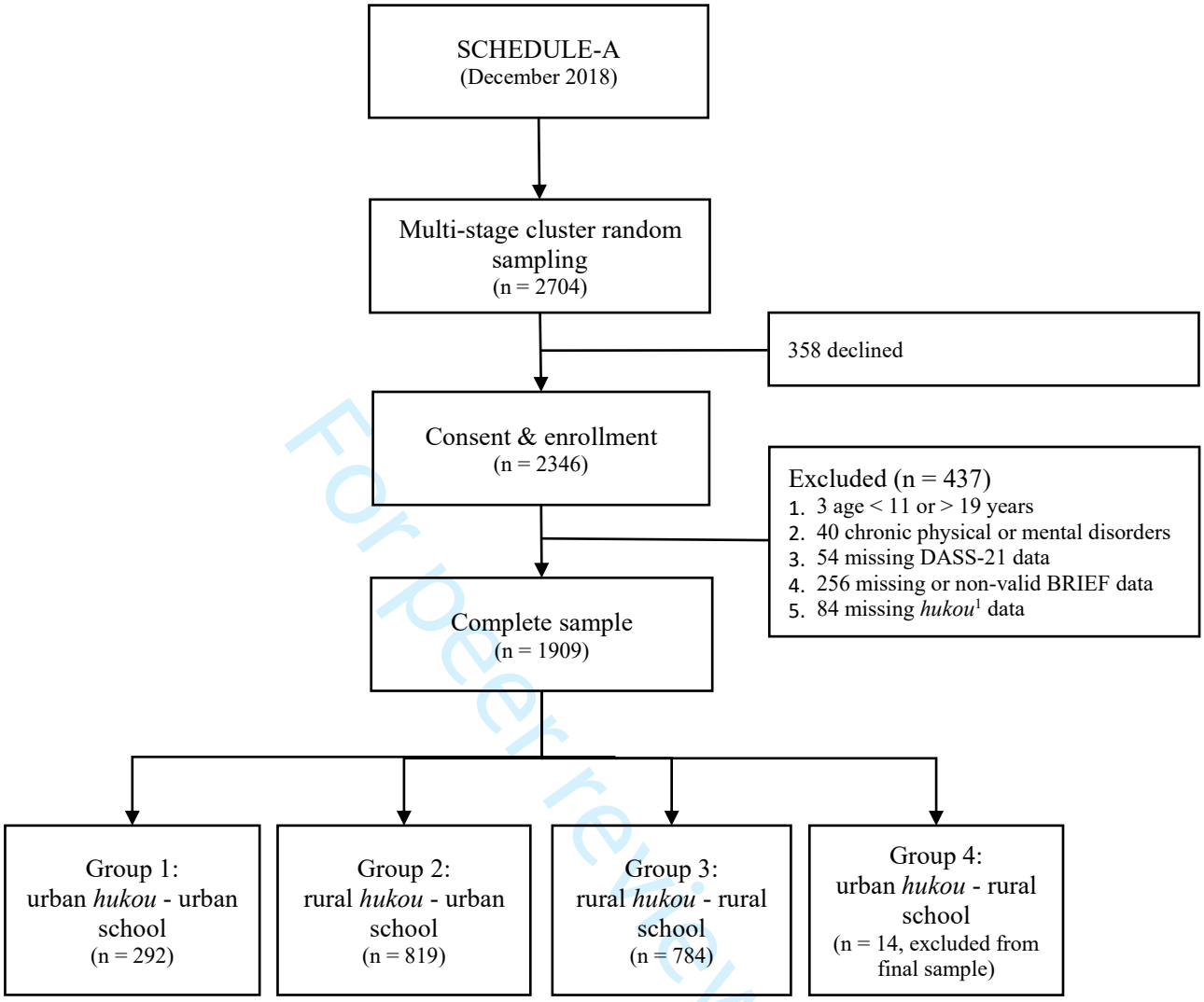

Figure 1 Flowchart of the participants

BRIEF, the Behavior Rating Inventory of Executive Function; DASS-21, the Depression Anxiety and Stress Scale-21; SCHEDULE-A, the Study of the Shanghai Children's Health, Education and Lifestyle Evaluation-Adolescents.

[1] Household registration system in China that was established officially in 1958, based on it each Chinese citizen can be classified into urban or rural origin according to his/her permanent residential area.

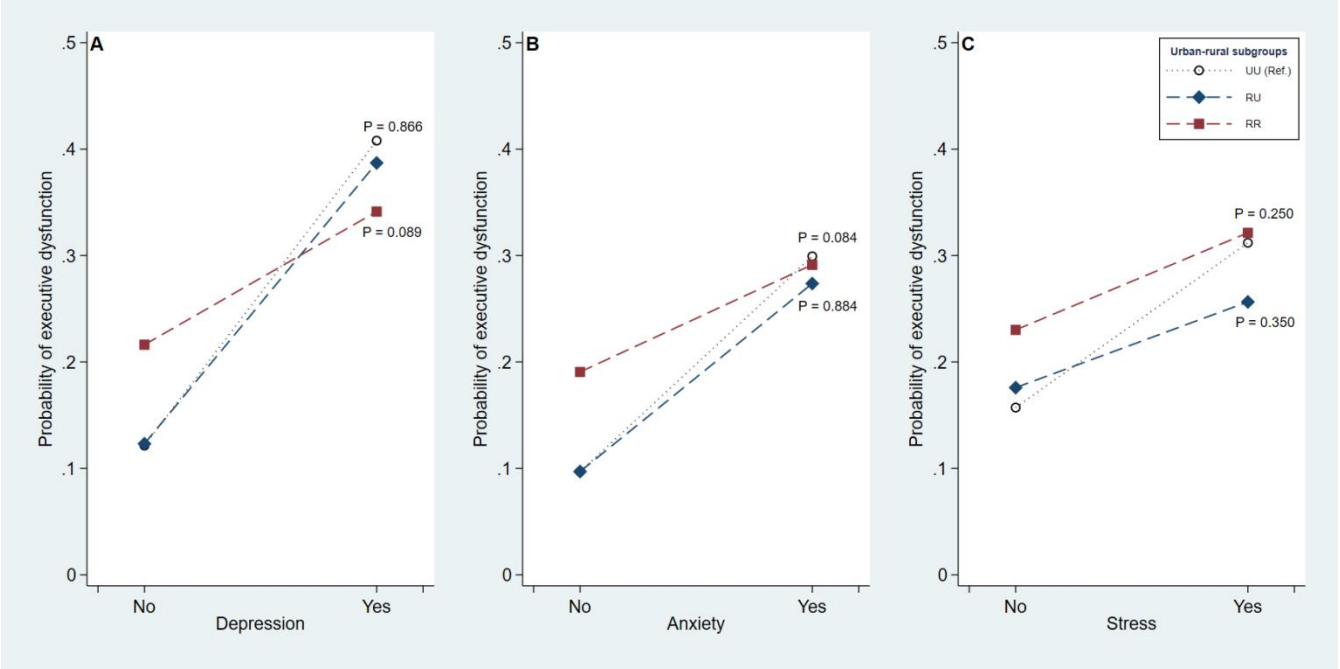

Figure 2 Interactive effects of urban-rural subgroup and mental health symptoms on executive dysfunction

RR, rural hukou and rural school group; RU, rural hukou and urban school group; UU, urban hukou and urban school group.

All models were adjusted for sociodemographic characteristics (i.e., age, sex, parental education level, and gross family income) and individual behaviors (screen time, night sleep duration, and physical activity).

P values indicated whether each interactive effect of urban-rural subgroups and mental health symptoms on executive dysfunction reached statistical significance.

Method S

Study of the Shanghai Children's Health, Education, and Lifestyle Evaluation-Adolescents (SCHEDULE-A), a population-based cross-sectional survey, was designed to investigate the individual, household, and school-level factors of adolescent physical and mental health across regions with different social and economic development status. In SCHEDULE-A, one first-tier city (Shanghai, November 2017) and one third-tier city (Shangrao, December 2018) were chosen in order to include a sample that represented both socioeconomically developed and underdeveloped regions. The city tier distinctions were based on a classification system released by China Business News magazine in 2017, which was assessed according to five indicators: concentration of commercial resources, city's pivotability, citizen vitality, variety of lifestyle, and flexibility in the future. Using a multi-stage cluster random sampling strategy (district-school-class), we recruited a representative school sample from the two selected cities. For the current study, we used data exclusively collected from Shangrao prefecture.

The multi-stage cluster sampling approach used was as follows. First, the primary sampling units (i.e., district or county) were selected according to the per capita disposable income (PCDI) of Chinese residents in 2016 (**Table S1**). The Shangrao city has 12 administrative districts/counties, and all districts/counties fell into either the fourth or fifth (the two lowest) quintiles of the average PCDI among Chinese residents. Specifically, two districts/counties were in the fourth PCDI quintile and ten districts/counties were in the fifth PCDI quintile. After ranking the PCDI of the districts/counties in descending order, we sampled one district/county using simple random sampling in the fourth PCDI quintile and three counties in the fifth PCDI quintile. Overall, four districts/counties were selected as primary sampling units. Second, in each district/county selected, two junior high schools and two senior high schools stratified by rural and urban area were randomly selected, with a total of 16 schools. Finally, one class from each grade of the included schools was randomly selected, and all students were invited to take part in the survey.

Through this sampling method, 2,704 students were selected, accounting for 1.5% percent of all the junior-senior high school students in the four sampled counties. A total of 2,346 students (86.8% response rate) agreed to participate, and 1,895 students (48.8% male) were analyzed after data cleaning (**Fig. 1**, **Table 1**). Besides age, there were no significant differences between the analyzed sample and excluded sample in terms of demographic characteristics.

Table S1 The per capita disposal income (PCDI) of the selected districts/counties in 2016

City	District/county	PCDI (RMB/Year)[2]
Shangrao, underdeveloped[1]		
	Xinzhou District	14,358 (about 2,190 USD)
	Yushan County	12,788 (about 1,950 USD)
	Wuyuan County	10,750 (about 1,639 USD)
	Poyang County	8,574 (about 1,308 USD)

[1] A relatively low socioeconomic development city located in downstream Yangtze River in southeast China.

[2] According to the PCDI of Chinese residents in 2016, the average PCDI from the lowest quintile to the highest quintile are 5,529, 12,899, 20,924, 31,990 and 59,209 RMB/year.

Table S2 Risk factors for mental health symptoms and executive dysfunction

	Depression		Anxiety		Stress		Executive dysfunction	
	Unadjusted	Adjusted [1]	Unadjusted	Adjusted [1]	Unadjusted	Adjusted [1]	Unadjusted	Adjusted [1]
Urban-rural subgroup								
UU	Ref.	Ref.	Ref.	Ref.	Ref.	Ref.	Ref.	Ref.
RU	1.32 (0.95, 1.83)	1.10 (0.61, 1.98)	**1.56 (1.19, 2.05)****	1.32 (0.85, 2.05)	**1.54 (1.06, 2.22)***	1.46 (0.76, 2.80)	1.09 (0.77, 1.53)	0.77 (0.51, 1.16)
RR	**1.48 (1.07, 2.05)***	1.02 (0.59, 1.77)	**2.00 (1.52, 2.63)*****	1.35 (0.77, 2.39)	**1.57 (1.09, 2.28)***	1.41 (0.95, 2.10)	1.35 (0.96, 1.90)	0.81 (0.35, 1.84)
Sociodemographics								
Age, y	/	0.99 (0.93, 1.05)	/	0.99 (0.93, 1.05)	/	0.99 (0.95, 1.03)	/	0.94 (0.82, 1.10)
Sex, female	/	**1.06 (1.02, 1.10)****	/	**1.39 (1.16, 1.66)*****	/	**1.15 (1.01, 1.32)***	/	0.97 (0.77, 1.21)
Parental education, high school or higher	/	1.14 (0.83, 1.56)	/	**0.82 (0.68, 0.98)***	/	1.26 (1.00, 1.58)	/	**0.68 (0.55, 0.84)*****
Family income, ≥ 50,000 RMB	/	0.87 (0.68, 1.10)	/	**0.85 (0.73, 0.99)***	/	0.97 (0.77, 1.22)	/	**0.61 (0.39, 0.97)***
Individual behaviors								
Screen time								
Passive screen time, ≥ 2h	/	**1.60 (1.22, 2.11)****	/	1.24 (0.81, 1.91)	/	1.23 (0.99, 1.53)	/	1.17 (0.76, 1.78)
Interactive screen time, ≥ 2h	/	**1.20 (1.05, 1.37)****	/	**1.89 (1.41, 2.54)*****	/	**1.36 (1.13, 1.64)****	/	**1.45 (1.29, 1.62)*****
Night sleep duration, short	/	0.93 (0.84, 1.02)	/	1.19 (0.98, 1.45)	/	1.13 (0.79, 1.62)	/	**0.74 (0.58, 0.96)***
Physical activity								
Low	/	Ref.	/	Ref.	/	Ref.	/	Ref.
Moderate	/	0.73 (0.38, 1.39)	/	**0.78 (0.68, 0.90)****	/	**0.64 (0.45, 0.92)***	/	0.80 (0.55, 1.18)
High	/	**0.84 (0.71, 0.98)***	/	0.74 (0.51, 1.09)	/	**0.69 (0.56, 0.84)*****	/	0.85 (0.54, 1.34)

RR, rural hukou and rural school group; RU, rural hukou and urban school group; UU, urban hukou and urban school group.

[1] Adjusted for sociodemographic characteristics (i.e., age, sex, parental education level, and gross family income) and individual behaviors (screen time, night sleep duration, and physical activity).

*P <0.05, **P <0.01, ***P <0.001.

Table S3 Adjusting risk factors step by step for mental health symptoms

	Depression		Anxiety		Stress	
	OR (95% CI)	R^2	OR (95% CI)	R^2	OR (95% CI)	R^2
Model 1		0.003		0.010		0.004
Urban-rural subgroup						
UU	Ref.		Ref.		Ref.	
RU	1.32 (0.95, 1.83)		**1.56 (1.19, 2.05)****		**1.54 (1.06, 2.22)***	
RR	**1.48 (1.07, 2.05)***		**2.00 (1.52, 2.63)*****		**1.57 (1.09, 2.28)***	
Model 2		0.004		0.010		0.004
Urban-rural subgroup						
UU	Ref.		Ref.		Ref.	
RU	1.32 (0.95, 1.83)		**1.56 (1.19, 2.05)****		**1.54 (1.06, 2.22)***	
RR	**1.45 (1.04, 2.01)***		**1.98 (1.51, 2.61)*****		**1.55 (1.07, 2.24)***	
Age, y	0.96 (0.90, 1.01)		0.98 (0.93, 1.03)		0.97 (0.90, 1.03)	
Model 3		0.003		0.013		0.004
Urban-rural subgroups						
UU	Ref.		Ref.		Ref.	
RU	1.32 (0.95, 1.83)		**1.57 (1.20, 2.05)****		**1.54 (1.06, 2.22)***	
RR	**1.48 (1.07, 2.05)***		**2.00 (1.52, 2.63)*****		**1.57 (1.09, 2.27)***	
Sex, female	1.02 (0.83, 1.26)		**1.32 (1.10, 1.58)****		1.13 (0.90, 1.42)	
Model 4		0.003		0.012		0.004
Urban-rural subgroup						
UU	Ref.		Ref.		Ref.	
RU	1.32 (0.94, 1.84)		**1.44 (1.08, 1.91)***		**1.6 (1.09, 2.34)***	
RR	**1.45 (1.03, 2.04)***		**1.81 (1.36, 2.42)*****		**1.65 (1.12, 2.43)***	
Parental education, high school or higher	0.98 (0.77, 1.26)		**0.78 (0.63, 0.97)***		1.11 (0.85, 1.46)	
Model 5		0.003		0.012		0.003
Urban-rural subgroup						
UU	Ref.		Ref.		Ref.	
RU	1.20 (0.85, 1.71)		**1.58 (1.17, 2.12)****		1.45 (0.97, 2.16)	
RR	1.38 (0.96, 1.97)		**1.93 (1.42, 2.62)*****		**1.54 (1.02, 2.31)***	
Family income, ≥ 50,000 RMB	0.86 (0.68, 1.10)		**0.80 (0.65, 0.99)***		1.00 (0.77, 1.30)	
Model 6		**0.018**		**0.024**		**0.011**
Urban-rural subgroup						
UU	Ref.		Ref.		Ref.	
RU	1.15 (0.83, 1.60)		**1.37 (1.04, 1.81)***		1.39 (0.96, 2.01)	
RR	1.16 (0.82, 1.63)		**1.54 (1.16, 2.05)****		1.29 (0.88, 1.90)	
Passive screen time, ≥ 2h	**1.71 (1.36, 2.15)*****		**1.39 (1.14, 1.70)****		**1.34 (1.05, 1.71)***	
Interactive screen time, ≥ 2h	1.20 (0.95, 1.51)		**1.51 (1.23, 1.87)*****		**1.30 (1.01, 1.67)***	
Model 7		0.003		0.011		0.004
Urban-rural subgroup						
UU						
RU	1.31 (0.94, 1.81)		**1.57 (1.20, 2.06)****		**1.55 (1.07, 2.25)***	
RR	**1.40 (1.00, 1.96)***		**2.09 (1.58, 2.76)*****		**1.66 (1.14, 2.42)****	
Sleep duration, short	0.91 (0.74, 1.14)		1.15 (0.95, 1.39)		1.12 (0.89, 1.42)	
Model 8		0.006		0.011		0.009
Urban-rural subgroup						
UU	Ref.		Ref.		Ref.	
RU	1.29 (0.93, 1.79)		**1.56 (1.19, 2.05)****		**1.53 (1.06, 2.21)***	
RR	**1.42 (1.03, 1.98)***		**1.98 (1.50, 2.60)*****		**1.54 (1.07, 2.23)***	
Physical activity						
Low	Ref.		Ref.		Ref.	
Moderate	**0.75 (0.57, 0.97)***		0.81 (0.65, 1.02)		**0.63 (0.48, 0.83)****	
High	1.00 (0.77, 1.29)		0.85 (0.68, 1.07)		**0.75 (0.57, 0.99)***	
Model 9		0.015		**0.031**		0.008
Urban-rural subgroup						
UU	Ref.		Ref.		Ref.	
RU	1.11 (0.77, 1.59)		1.29 (0.95, 1.77)		1.43 (0.95, 2.14)	
RR	1.11 (0.75, 1.63)		1.32 (0.94, 1.84)		1.38 (0.90, 2.14)	
Parental education, high school or higher	1.13 (0.85, 1.49)		0.82 (0.64, 1.05)		1.23 (0.91, 1.66)	
Family income, ≥ 50,000 RMB	0.84 (0.66, 1.08)		0.83 (0.67, 1.03)		0.95 (0.73, 1.25)	
Passive screen time, ≥ 2h	**1.57 (1.22, 2.03)****		1.21 (0.96, 1.52)		1.20 (0.91, 1.57)	
Interactive screen time, ≥ 2h	1.21 (0.93, 1.57)		**1.79 (1.42, 2.27)*****		1.27 (0.95, 1.69)	

RR, rural hukou and rural school group; RU, rural hukou and urban school group; UU, urban hukou and urban school group.
*P <0.05, **P <0.01, ***P <0.001.

Table S4 Interactive effects of urban-rural subgroup and mental health symptoms on executive dysfunction

	Executive dysfunction			
	Unadjusted		Adjusted	
	OR (95% CI)	P value	OR (95% CI)	P value
Model a				
Depression	4.64 (2.43, 8.85)	**< 0.001**	5.31 (2.01, 14.02)	**0.001**
RU	0.96 (0.61, 1.50)	0.845	0.73 (0.46, 1.15)	0.171
RR	1.69 (1.09, 2.61)	**0.018**	1.12 (0.36, 3.46)	0.848
RU*Depression	1.10 (0.52, 2.32)	0.797	0.89 (0.23, 3.50)	0.866
RR*Depression	0.42 (0.20, 0.87)	**0.020**	0.36 (0.11, 1.17)	0.089
Model b				
Anxiety	3.67 (1.96, 6.85)	**< 0.001**	4.13 (1.29, 13.3)	**0.017**
RU	0.95 (0.52, 1.70)	0.852	0.73 (0.27, 2.00)	0.546
RR	1.65 (0.94, 2.93)	0.083	1.26 (0.43, 3.68)	0.673
RU*Anxiety	1.00 (0.48, 2.09)	0.997	0.88 (0.15, 5.26)	0.884
RR*Anxiety	0.57 (0.28, 1.16)	0.122	0.43 (0.16, 1.12)	0.084
Model c				
Stress	2.29 (1.10, 4.77)	**0.028**	2.52 (0.96, 6.61)	0.061
RU	1.11 (0.75, 1.63)	0.615	0.80 (0.43, 1.49)	0.489
RR	1.38 (0.94, 2.03)	0.103	0.85 (0.35, 2.07)	0.723
RU*Stress	0.76 (0.33, 1.75)	0.521	0.65 (0.27, 1.60)	0.350
RR*Stress	0.75 (0.33, 1.72)	0.498	0.64 (0.30, 1.37)	0.250

RR, rural hukou and rural school group; RU, rural hukou and urban school group.

[1] All models were adjusted for sociodemographic characteristics (i.e., age, sex, parental education level, and gross family income) and individual behaviors (screen time, night sleep duration, and physical activity).

Table S5 Simple effects of urban-rural subgroups on executive dysfunction stratified by mental health symptoms[1]

	Executive dysfunction		
	OR (95% CI)	*z* value	P value
Depression state			
No depression			
Urban-rural subgroup			
UU	Ref.		
RU	0.73 (0.41, 1.29)	-1.09	0.277
RR	1.02 (0.35, 2.93)	0.03	0.975
Depression			
Urban-rural subgroup			
UU	Ref.		
RU	0.58 (0.23, 1.52)	-1.10	0.270
RR	0.40 (0.21, 0.75)	-2.84	**0.004**
Anxiety state			
No anxiety			
Urban-rural subgroup			
UU	Ref.		
RU	0.78 (0.29, 2.13)	-0.48	0.631
RR	1.55 (0.53, 4.48)	0.80	0.422
Anxiety			
Urban-rural subgroup			
UU	Ref.		
RU	0.61 (0.26, 1.46)	-1.11	0.269
RR	0.49 (0.22, 1.08)	-1.76	0.078
Stress state			
No stress			
Urban-rural subgroup			
UU			
RU	0.82 (0.41, 1.65)	-0.55	0.585
RR	0.84 (0.29, 2.39)	-0.33	0.742
Stress			
Urban-rural subgroup			
UU	Ref.		
RU	0.44 (0.16, 1.21)	-1.59	0.112
RR	0.57 (0.20, 1.59)	-1.08	0.281

RR, rural hukou and rural school group; RU, rural hukou and urban school group; UU, urban hukou and urban school group.

[1] All models were adjusted for sociodemographic characteristics (i.e., age, sex, parental education level, and gross family income) and individual behaviors (screen time, night sleep duration, and physical activity).

Table S6 Interactive effects of urban-rural subgroups and mental health symptoms on executive dysfunction (imputed data)

	Executive dysfunction			
	Unadjusted		Adjusted	
	OR (95% CI)	P value	OR (95% CI)	P value
Model a				
Depression	4.64 (2.43, 8.85)	**< 0.001**	5.20 (1.89, 14.27)	**0.001**
RU	0.96 (0.61, 1.50)	0.845	0.72 (0.54, 0.95)	**0.021**
RR	1.69 (1.09, 2.61)	**0.018**	0.98 (0.39, 2.46)	0.969
RU*Depression	1.10 (0.52, 2.32)	0.797	0.88 (0.27, 2.87)	0.828
RR*Depression	0.42 (0.20, 0.87)	**0.020**	0.37 (0.11, 1.21)	0.101
Model b				
Anxiety	3.67 (1.96, 6.85)	**< 0.001**	3.64 (1.29, 10.22)	**0.014**
RU	0.95 (0.52, 1.70)	0.852	0.71 (0.32, 1.58)	0.403
RR	1.65 (0.94, 2.93)	0.083	0.97 (0.38, 2.48)	0.947
RU*Anxiety	1.00 (0.48, 2.09)	0.997	0.94 (0.18, 4.96)	0.939
RR*Anxiety	0.57 (0.28, 1.16)	0.122	0.55 (0.24, 1.27)	0.162
Model c				
Stress	2.29 (1.10, 4.77)	**0.028**	2.35 (0.83, 6.66)	0.107
RU	1.11 (0.75, 1.63)	0.615	0.78 (0.47, 1.31)	0.348
RR	1.38 (0.94, 2.03)	0.103	0.75 (0.37, 1.54)	0.438
RU*Stress	0.76 (0.33, 1.75)	0.521	0.71 (0.22, 2.31)	0.566
RR*Stress	0.75 (0.33, 1.72)	0.498	0.71 (0.30, 1.71)	0.449

RR, rural hukou and rural school group; RU, rural hukou and urban school group.

[1] All models were adjusted for sociodemographic characteristics (i.e., age, sex, parental education level, and gross family income) and individual behaviors (screen time, night sleep duration, and physical activity).

Table S7 Simple effects of mental health symptoms on executive dysfunction stratified by urban-rural subgroup1 (imputed data)

	Executive dysfunction		
	OR (95% CI)	*z* value	P value
UU group			
Depression, score ≥ 14	6.21 (3.37, 11.45)	5.86	**< 0.001**
Anxiety, score ≥ 10	4.69 (1.71, 12.85)	3.00	**0.003**
Stress, score ≥ 19	2.98 (1.65, 5.40)	3.61	**< 0.001**
RU group			
Depression, score ≥ 14	4.78 (1.95, 11.72)	3.42	**0.001**
Anxiety, score ≥ 10	3.33 (1.33, 8.34)	2.56	**0.010**
Stress, score ≥ 19	1.67 (0.84, 3.33)	1.46	0.143
RR group			
Depression, score ≥ 14	1.91 (0.92, 3.96)	1.75	0.080
Anxiety, score ≥ 10	2.04 (1.39, 2.98)	3.67	**< 0.001**
Stress, score ≥ 19	1.68 (1.23, 2.31)	3.23	**0.001**

RR, rural hukou and rural school group; RU, rural hukou and urban school group; UU, urban hukou and urban school group.

[1] Adjusted for sociodemographic characteristics (i.e., age, sex, parental education level, and gross family income) and individual behaviors (screen time, night sleep duration, and physical activity).

Table S8 Simple effects of urban-rural subgroups on executive dysfunction stratified by mental health symptoms1 (imputed data)

	Executive dysfunction		
	OR (95% CI)	*z* value	P value
Depression state			
No depression			
Urban-rural subgroup			
UU	Ref.		
RU	0.72 (0.51, 1.01)	-1.88	0.060
RR	0.90 (0.39, 2.08)	-0.25	0.801
Depression			
Urban-rural subgroup			
UU	Ref.		
RU	0.61 (0.29, 1.28)	-1.31	0.191
RR	0.39 (0.23, 0.68)	-3.36	**0.001**
Anxiety state			
No anxiety			
Urban-rural subgroup			
UU	Ref.		
RU	0.76 (0.32, 1.8)	-0.62	0.538
RR	1.08 (0.40, 2.95)	0.15	0.878
Anxiety			
Urban-rural subgroup			
UU	Ref.		
RU	0.64 (0.25, 1.62)	-0.95	0.344
RR	0.50 (0.30, 0.86)	-2.54	**0.011**
Stress state			
No stress			
Urban-rural subgroup			
UU	Ref.		
RU	0.79 (0.44, 1.41)	-0.81	0.419
RR	0.72 (0.30, 1.73)	-0.73	0.463
Stress			
Urban-rural subgroup			
UU	Ref.		
RU	0.51 (0.16, 1.66)	-1.12	0.265
RR	0.61 (0.23, 1.62)	-0.99	0.323

RR, rural hukou and rural school group; RU, rural hukou and urban school group; UU, urban hukou and urban school group.

[1] All models were adjusted for sociodemographic characteristics (i.e., age, sex, parental education level, and gross family income) and individual behaviors (screen time, night sleep duration, and physical activity).

STROBE Statement—Checklist of items that should be included in reports of ***cross-sectional studies***

	Item No	Recommendation	Page No
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract	4
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found	4-5
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	7-9
Objectives	3	State specific objectives, including any prespecified hypotheses	9
Methods			
Study design	4	Present key elements of study design early in the paper	9
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	9
Participants	6	(*a*) Give the eligibility criteria, and the sources and methods of selection of participants	9, Method S
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	10-12
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	*10-12*
Bias	9	Describe any efforts to address potential sources of bias	11-12
Study size	10	Explain how the study size was arrived at	Figure 1, Method S
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	10-12
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding	12
		(*b*) Describe any methods used to examine subgroups and interactions	12
		(*c*) Explain how missing data were addressed	12
		(*d*) If applicable, describe analytical methods taking account of sampling strategy	12
		(*e*) Describe any sensitivity analyses	12
Results			
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	Figure 1
		(b) Give reasons for non-participation at each stage	Figure 1
		(c) Consider use of a flow diagram	Figure 1
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	13
		(b) Indicate number of participants with missing data for each variable of interest	Figure 1

Outcome data	15*	Report numbers of outcome events or summary measures	Table 2
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	13-14, Table 3, 5-6, 9
		(*b*) Report category boundaries when continuous variables were categorized	Table 2
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	Not applicable
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	14
Discussion			
Key results	18	Summarise key results with reference to study objectives	14-15
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	17
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	17
Generalisability	21	Discuss the generalisability (external validity) of the study results	17
Other information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	18

*Give information separately for exposed and unexposed groups.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.

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Association between mental health and executive dysfunction and the moderating effect of urban-rural subpopulation in general adolescents from Shangrao, China, a population-based cross-sectional study

Qingmin Lin[1], Cody Abbey[2], Yunting Zhang[3], Guanghai Wang[1,4,5,6], Jinkui Lu[7], Sarah-Eve Dill[2], Qi Jiang[2], Manpreet Kaur Singh[8], Xinshu She[8], Huan Wang[9], Scott Rozelle[2], and Fan Jiang[1,4,5,6,#]

Affiliations:

[1]Pediatric Translational Medicine Institution, Shanghai Children's Medical Center, School of Medicine, Shanghai Jiao Tong University, Shanghai 200127, China.

[2]Freeman Spogli Institute for International Studies, Stanford University, Stanford, CA, USA.

[3]Child Health Advocacy Institute, Shanghai Children's Medical Center, School of Medicine, Shanghai Jiao Tong University, Shanghai 200127, China.

[4]Department of Developmental and Behavioral Pediatrics, Shanghai Children's Medical Center, School of Medicine, Shanghai Jiao Tong University, Shanghai 200127, China.

[5]Ministry of Education-Shanghai Key Laboratory of Children's Environmental Health, Xinhua Hospital, School of Medicine, Shanghai Jiao Tong University, Shanghai 200092, China.

[6]Shanghai Center for Brain Science and Brain-Inspired Technology, Shanghai 201602, China.

[7]Department of Physical Education, Shangrao Normal University, Shangrao 334001, China.

[8]Stanford University School of Medicine, Stanford, CA, USA.

[9]Stanford Center on China's Economy and Institutions, Stanford University, Stanford, CA, USA.

[#]Corresponding author:

Fan Jiang, Pediatric Translational Medicine Institution, Department of Developmental and Behavioral Pediatrics, Shanghai Children's Medical Center, School of Medicine, Shanghai Jiao Tong University, 1678 Dongfang Rd. Shanghai 200127, China. Tel: 86-21-38626012; Fax: 86-21-58706129; Email: fanjiang@shsmu.edu.cn.

Abstract

Objectives To examine the association between mental health and executive dysfunction in general adolescents, and to identify whether home residence and school location would moderate that association.

Design A population-based cross-sectional study.

Setting A subsample of the SCHEDULE-A project. 16 sampled schools in Shangrao city located in downstream Yangtze River in southeast China (December 2018).

Participants 1895 adolescents (48.8% male) which were divided into three subpopulations: a.) adolescents who have urban *hukou* (i.e., household registration in China) and attend urban schools (UU, n = 292); b.) adolescents who have rural *hukou* and attend urban schools (RU, n = 819); and c.) adolescents who have rural *hukou* and attend rural schools (RR, n = 784).

Measures The Depression Anxiety and Stress Scale-21 was used to assess adolescent mental health symptoms, and the Behavior Rating Inventory of Executive Function (parent form) was applied to measure adolescent executive dysfunction in nature setting.

Results Mental health symptoms were common (depression: 25.2%, anxiety: 53.0%, stress: 19.7%) in our sample, and the prevalence rates were lower among UU adolescents than those among the RR and RU, with inter-subgroup differences in screen exposure time explaining most of the variance. We found the three types of symptoms were strongly associated with executive dysfunction in general adolescents. We also observed a marginal moderating effect of urban-rural subgroup on the associations: UU

adolescents with depression (OR = 6.74, 95% CI: 3.75-12.12) and anxiety (OR = 5.56, 95% CI: 1.86-16.66) had a higher executive dysfunction risk when compared to RR youths with depression (OR = 1.93, 95% CI: 0.91-4.12) and anxiety (OR = 1.80, 95% CI: 1.39-2.33), respectively.

Conclusions Rural adolescents experienced more mental health symptoms, whereas urban individuals with mental health problems had a higher executive dysfunction risk.

Keywords: adolescents, mental health, executive dysfunction, urban-rural subpopulation

Strengths and limitations of this study

- ✧ This is a population-based cross-sectional survey using multi-stage cluster random sampling method.
- ✧ This study investigated the moderating effect of urban-rural subpopulation on the association between mental health and executive dysfunction among general adolescents.
- ✧ The data was collected from one relatively low socioeconomic development city in China, and the findings might not be generalizable to the national population.
- ✧ The study utilized sub-clinical cutoffs of executive dysfunction, and the measures of lifestyle behaviors were based on self-report.
- ✧ This is a cross-sectional study, we cannot make causal claims and cannot exclude the possibility that the results may be influenced by residual and unmeasured or unknown factors.

Introduction

Mental health disorders are the leading cause of global disability burden among youth, and approximately 21% of adolescents are at risk of some kind of mental disorders such as depression and anxiety.[1] One potential consequence of poor mental health is impairment to executive functions (EFs),[2] which refer to a collection of top-down mental processes against one's bottom-up automatic actions (including three core subcomponents: inhibitory control, working memory, and cognitive flexibility) that are necessary to make decisions and engage in purposeful, goal-driven, and future-oriented behaviors.[3] Executive dysfunction (EDF), also known as EF impairment, can negatively impact physical health (e.g., obesity, overeating, poor treatment adherence),[4 5] result in antisocial behavior (e.g., aggression, violence, and criminality),[6 7] and hinder academic and career success (e.g., poor school readiness and work productivity).[8]

While mental health illnesses can increase the risk of EDF, existing studies have been predominantly focused on clinical patients, such as those suffering from major depressive disorder,[9] and few studies were conducted among general adolescents. Nowadays, more and more adolescents are troubled with mental health problems, a significant percentage of which, however, are sub-clinical symptoms (i.e., those not meeting clinical diagnostic criteria). Given that sub-clinical symptoms of a psychological illness still meaningfully may increase EF impairment, it is crucial to explore whether mental health symptoms can increase EDF among general adolescents at a population level.

The link between mental health issues and EF in general adolescents was investigated by some studies. One community study recently indicated that depressive status as measured by an epidemiological screening scale was associated with lower cognitive flexibility and selective attention.[10] However, another population-based study including

adolescents from both urban and rural areas did not find a significant association.[11] One potential reason for these differences may be that certain social factors, such as adolescent living and study environments, may moderate that link, as the distribution of economic, healthcare, and educational resources,[12 13] as well as some lifestyle behaviors (e.g., physical activity, and screen exposure),[14 15] can vary significantly based on an adolescent's home residence or school location, particularly in developing nations with large urban-rural socioeconomic disparities.[16]

Urban regions typically receive a disproportionately larger share of economic investment and have higher quality of healthcare and educational environments than rural regions, which may mitigate the presence or reduce the impact of their mental health symptoms. Meanwhile, urban regions also have a number of stressors including dense population, as well as traffic and air pollution,[17 18] which may aggravate the mental health and EF relationship. In some contexts, rural adolescents relocating to urban areas with or without their parents (migrant) tend to have worse lifestyle behaviors such as more screen exposure time,[15] and may also face a unique set of adverse circumstances such as social stigma threat from peers,[19] which may in turn impact their mental health and EF. In light of these disparities, it is possible that the associations between mental health symptoms and EDF may differ by adolescent home residence and school location, yet no studies have examined their moderating effects on those associations in general sample.

China is one of the most populous developing countries and has a large number of adolescent students that belong to all three of these subpopulation categories (i.e., local urban, local rural, and rural-urban migrant), which gave us a unique opportunity to investigate the association between mental health and EDF across different urban-rural subgroups. Specifically, in China, a household registration system (i.e., *hukou*)

established officially in 1958 classifies each Chinese citizen as either urban or rural origin according to his/her permanent residential area.[19] By taking into account adolescent *hukou* and school location, we can define three subgroups: a.) adolescents who have urban *hukou* and attend urban schools (UU); b.) adolescents who have rural *hukou* and attend urban schools (RU); and c.) adolescents who have rural *hukou* and attend rural schools (RR). Therefore, using a population-based Chinese sample, we aimed to measure whether or not the associations between three common mental health symptoms (i.e., depression, anxiety, and stress) and EDF among general adolescents vary across different urban-rural subpopulations.

Methods

Participants

Participants were part of the Study of the Shanghai Children's Health, Education, and Lifestyle Evaluation-Adolescents (SCHEDULE-A), which is a population-based cross-sectional survey investigating risk factors of the physical and mental health of general adolescents. The present study was conducted in Shangrao (December 2018), a relatively socioeconomically underdeveloped city located in downstream Yangtze River in southeast China. The multi-stage cluster random sampling method we used was reported in prior study[20]. Briefly, based on the per capita disposable income of Chinese residents in 2016, four districts/counties were selected, and four schools (two lower secondary and two upper secondary) stratified by rural and urban areas were randomly chosen from each district/county, then one class from each grade in the sampled 16 schools was randomly selected, and finally all students in the selected classes were invited to participate in the survey. Ethical approval was granted by the Shanghai Children's Medical Center Human Ethics Committee (SCMCIRB-K2018103). We obtained written informed consents from all parents and adolescents.

Main variables

Urban-rural subgroups

We obtained the *hukou* information through parent report and school location data by referring to the official administrative urban-rural designations, and then divided the final sample into three major subpopulations (**Figure 1**): UU (n = 292), RU (n = 819) and RR (n = 784). Due to a small number of adolescents who had urban *hukou* and attended rural schools (n = 14), we did not include them in the current analysis.

Mental health symptoms

The Depression Anxiety and Stress Scale-21 (DASS-21) that has been validated among the Chinese student population was used to measure three common mental health conditions (i.e., depression, anxiety, and stress).[21] Each domain has seven items for which adolescents indicated how often they experienced the described symptom in the last week on a 4-point scale from 0 "does not apply to me at all" to 3 "applies to me very much or most of the time." The score for each domain was summed and multiplied by 2, and adolescents who scored "moderate to extremely severe" by cutoffs of ≥ 14, ≥ 10, and ≥ 19 were classified as having potential depression, anxiety, and stress conditions, respectively.

Executive dysfunction

The Behavior Rating Inventory of Executive Function (BRIEF) was used to assess adolescent EF performance,[22] which has demonstrated an acceptable reliability and validity among Chinese youth.[23] Unlike the traditional task-based testing conducted by a well trained professional within a highly structured laboratory, the BRIEF, a questionnaire-based measurement, was designed to capture an individual's everyday behavioral and emotional aspects of EF in nature environment, and is a reliable and practical tool used in a large epidemiological study. In the current study, we used the

parent report form with 86 items, and for each item, parents were asked to rate their adolescents' specific behaviors in the past six months using a 3-point scale (i.e., never, sometimes, and often). We checked the raw data based on two validity indexes (i.e., negativity < 5 and inconsistency < 7) to reduce reporting bias according to the BRIEF manual. We calculated the overall raw score (i.e., global executive composite) by adding up the following eight index scores: inhibit, emotional control, shift, initiate, working memory, plan/organize, organization of materials, and monitor. T-scores were computed based on sex- and age-specific norms, and we defined T-scores > 60 and > 65 as potentially sub-clinical and clinical EDF, respectively.

Covariates

Parents or other primary caregivers reported sociodemographic information, including parental education level, gross family income, as well as the adolescent's age, sex, and chronic disease history. Adolescents were asked to report their lifestyle behaviors. Screen exposure time was measured by two widely used questions: in the last month, on average, the total time he/she spent per day on (1) sitting and watching television or videos, and (2) playing games using device such as cellphone, iPAD, PlayStation, etc.[24] Each response was then dichotomized, with exposure time above 2 hours/day indicating excessive passive and interactive screen time, respectively. The average night sleep duration was calculated by a weighted formula (5*weekdays+2*weekends)/7 based on responses to the questions "At what time do you usually go to bed and get up on weekdays and weekends, respectively?" We defined shorter sleepers as students whose average night sleep duration was less than 9, 8, and 7 hours for students aged 12-13, 14-17 and ≥ 18 years, respectively.[25] Physical activity was examined using the short Chinese version of the International Physical Activity Questionnaire (IPAQ), and then categorized into low, moderate, and high levels.[26]

Statistical analysis

Participant characteristics stratified by the three urban-rural subgroups were presented by means (SD) and frequencies (%), and their differences across the subgroups were tested by ANOVA (or Kruskal-Wallis) and chi-squared test for continuous and categorical variables, respectively.

To achieve our objectives, we first explored risk factors of mental health symptoms and executive dysfunction using a logistic model with cluster-robust standard error. The potential risk factors were urban-rural subgroup, sociodemographic characteristics (i.e., age, sex, parental education level, and gross family income), and individual behaviors (screen time, night sleep duration, and physical activity). Second, we measured the association of urban-rural subgroup and mental health symptoms with sub-clinical EDF (due to a low prevalence of clinical EDF, see **Table 1**). Third, we examined the moderating effect of urban-rural subgroup on the relationship of mental health symptoms and EDF (i.e., adding an interactive term in each model, such as RR*depression). Finally, we determined the simple effect of the association between mental health symptoms and EDF stratified by urban-rural subgroup. Furthermore, we also performed a multiple imputation using chained equations with 20 imputed datasets and 10 burn-ins for each dataset to estimate the missing values. To test whether substantial differences existed due to imputation, we compared the results before and after the data imputation.

All data analyses were performed with Stata 15.0, and $P < 0.05$ with two-sided was set as statistical significance.

Table 1 Participant characteristics stratified by urban-rural subgroup

	Total (n = 1895)	Urban-rural subgroup				
		UU (n = 292)	RU (n = 819)	RR (n = 784)	Chi-square	P value
Sociodemographics						
Age, y	15.33 ± 1.76	15.53 ± 1.62	15.56 ± 1.69	15.02 ± 1.83	46.86	**< 0.001**
Sex					1.03	0.598
Boys	925 (48.8)	144 (49.3)	409 (49.9)	372 (47.5)		
Girls	970 (51.2)	148 (50.7)	410 (50.1)	412 (52.6)		
Parental education level					268.24	**< 0.001**
Lower than high school	1338 (72.9)	118 (41.0)	606 (76.6)	614 (81.1)		
High school or higher	498 (27.1)	170 (59.0)	185 (23.4)	143 (18.9)		
Gross family income (RMB)					79.39	**< 0.001**
< 50,000	921 (58.7)	95 (38.6)	397 (56.7)	429 (69.0)		
≥ 50,000	647 (41.3)	151 (61.4)	303 (43.3)	193 (31.0)		
Individual behaviors						
Screen time						
Passive screen time, ≥ 2h	836 (44.1)	65 (22.3)	335 (40.9)	436 (55.7)	102.49	**< 0.001**
Interactive screen time, ≥ 2h	715 (37.8)	41 (14.0)	259 (31.6)	415 (53.0)	160.43	**< 0.001**
Night sleep duration, short	984 (52.5)	207 (70.9)	490 (60.1)	287 (37.3)	129.62	**< 0.001**
Physical activity					22.01	**< 0.001**
Low	547 (28.9)	85 (29.1)	222 (27.1)	240 (30.7)		
Moderate	709 (37.5)	136 (46.6)	315 (38.5)	258 (33.0)		
High	637 (33.7)	71 (24.3)	282 (34.4)	284 (36.3)		
Mental health symptoms[1]						
Depression, mean score	8.48 ± 8.10	7.42 ± 7.94[a]	8.14 ± 8.05[ab]	9.22 ± 8.15[c]	19.99	**< 0.001**
≥ 14	478 (25.2)	59 (20.2)	205 (25.0)	214 (27.3)	5.70	0.058
Anxiety, mean score	10.78 ± 7.91	8.70 ± 7.20[a]	10.58 ± 8.05[b]	11.76 ± 7.86[c]	36.68	**< 0.001**
≥ 10	1004 (53.0)	120 (41.1)	427 (52.1)	457 (58.3)	25.67	**< 0.001**
Stress, mean score	12.40 ± 8.30	11.07 ± 8.03[a]	12.45 ± 8.76[b]	12.83 ± 7.85[b]	11.86	**0.003**
≥ 19	374 (19.7)	42 (14.4)	168 (20.5)	164 (20.9)	6.28	**0.043**
Executive dysfunction[1]						
Global Executive Composite, mean score	50.77 ± 10.19	50.80 ± 9.86[ab]	49.81 ± 10.42[a]	51.78 ± 9.97[b]	15.44	**< 0.001**
Sub-clinical, > 60	400 (21.1)	54 (18.5)	162 (19.8)	184 (23.5)	4.69	0.096
Clinical, > 65	180 (9.5)	23 (7.9)	88 (10.7)	69 (8.8)	2.82	0.245

RR, rural hukou and rural school group; RU, rural hukou and urban school group; UU, urban hukou and urban school group.

[1] Multiple-comparison across the three urban-rural subgroups was conducted using non-parametric independent sample median tests. Columns with the same letters are not significantly different (P ≥0.05).

The bold words represent the P values less than 0.05.

Patient and public involvement

Patients or the public were not involved in the design, conduct, reporting or dissemination plans of this study.

Results

Sociodemographic and behavioral characteristics

Overall, of the final 1,895 adolescents, the mean age was 15.33 ± 1.76 years, and 925 (48.8%) were male. Additionally, 72.9% of adolescents' parents obtained lower education levels than high school, and 58.7% of their family income was lower than 50,000 RMB. Moreover, 44.1% and 37.8% participants had excessive passive and interactive screen time, respectively; 52.5% were shorter night sleepers; and 28.9% displayed low physical activity. There were significant sociodemographic and behavioral differences across the three urban-rural subgroups (except for sex). Specifically, the RR adolescents were younger and more likely to have parents with lower education level and family income. Furthermore, excessive screen time was more prevalent among the RU and RR adolescents, whereas short night sleep duration and less high physical activity were more common among the UU youths (**Table 1**).

Prevalence and risk factors of mental health symptoms

Overall, the prevalence of the three types of mental health symptoms was 25.2%, 53.0%, and 19.7% for depression, anxiety, and stress, respectively. There were significant differences across the three urban-rural subgroups, i.e., depression (UU, RU, and RR rates: 20.2%, 25.0%, and 27.3%; Chi-square = 5.70; P = 0.058), anxiety (41.1%, 52.1%, and 58.3%; Chi-square = 25.67; P < 0.001), and stress (14.4%, 20.5%, and 20.9%; Chi-square = 6.28; P = 0.043) (**Table 1**).

However, after adjusting for confounders, all significant differences disappeared (**Table S1**). We further conducted a post-hoc analysis by adjusting factors step by step

and found that the RR adolescents had a higher risk of depression, the RR and RU had a higher risk of anxiety, and the RR adolescents had a higher risk of stress, which were mainly due to more screen time. Additionally, the higher anxiety among RR and RU students was partly attributed to lower family income and parental education (**Table S2**).

Associations between mental health symptoms and executive dysfunction

After adjusting for confounders, all three types of mental health symptoms were significantly associated with EDF, with ORs being 3.22 (95% CI: 1.38-7.52), 2.68 (95% CI: 1.62-4.44), and 1.72 (95% CI: 1.07-2.75) for depression, anxiety, and stress, respectively (**Table 2**).

Moderating effect of urban-rural subgroup

Although we did not find a significant association between urban-rural subgroup and EDF (**Table S1**), we observed a marginal interactive effect of RR group and depression (P = 0.089) as well as RR group and anxiety (P = 0.084) on EDF (**Figure 2**, **Table S3**). In further simple analysis, we showed that the UU adolescents with depression (OR = 6.74, 95% CI: 3.75-12.12) and anxiety (OR = 5.56, 95% CI: 1.86-16.66) had a much higher risk of EDF than RR adolescents with depression (OR = 1.93, 95% CI: 0.91-4.12) and anxiety (OR = 1.80, 95% CI: 1.39-2.33) (**Table 3, Table S4)**. We also compared the results of complete-case and multiple-imputation analysis, and no much changes were found (**Table S5-S7**).

Table 2 Associations between mental health symptoms and executive dysfunction

	Executive dysfunction					
	Model a Unadjusted	Model a Adjusted[1]	Model b Unadjusted	Model b Adjusted[1]	Model c Unadjusted	Model c Adjusted[1]
Mental health symptoms						
Depression, score ≥ 14	**3.29 (2.6, 4.15)*** **	**3.22 (1.38, 7.52)** **	/	/	/	/
Anxiety, score ≥ 10	/	/	**2.88 (2.26, 3.67)*** **	**2.68 (1.62, 4.44)*** **	/	/
Stress, score ≥ 19	/	/	/	/	**1.80 (1.39, 2.32)*** **	**1.72 (1.07, 2.75)***
Urban-rural subgroup						
UU	/	Ref.	/	Ref.	/	Ref.
RU	/	0.72 (0.49, 1.05)	/	**0.70 (0.50, 0.98)***	/	0.74 (0.46, 1.17)
RR	/	0.78 (0.34, 1.79)	/	0.74 (0.34, 1.58)	/	0.78 (0.35, 1.76)
Sociodemographics						
Age, y	/	0.95 (0.81, 1.10)	/	0.95 (0.80, 1.11)	/	0.95 (0.82, 1.10)
Sex, female	/	0.95 (0.75, 1.20)	/	0.90 (0.67, 1.22)	/	0.95 (0.75, 1.21)
Parental education, ≥ high school	/	**0.64 (0.51, 0.79)*** **	/	**0.69 (0.57, 0.85)*** **	/	**0.66 (0.53, 0.81)*** **
Family income, ≥ 50,000 RMB	/	**0.62 (0.40, 0.95)***	/	**0.63 (0.39, 1.00)***	/	**0.61 (0.38, 0.99)***
Individual behaviors						
Screen time						
Passive screen time, ≥ 2h	/	1.06 (0.77, 1.44)	/	1.12 (0.79, 1.58)	/	1.15 (0.76, 1.74)
Interactive screen time, ≥ 2h	/	**1.41 (1.24, 1.61)*** **	/	**1.27 (1.11, 1.45)*** **	/	**1.41 (1.26, 1.58)*** **
Night sleep duration, short	/	**0.75 (0.58, 0.97)***	/	**0.71 (0.54, 0.95)***	/	**0.74 (0.57, 0.95)***
Physical activity						
Low	/	Ref.	/	Ref.	/	Ref.
Moderate	/	0.85 (0.50, 1.45)	/	0.83 (0.55, 1.26)	/	0.83 (0.55, 1.26)
High	/	0.86 (0.53, 1.40)	/	0.90 (0.57, 1.44)	/	0.88 (0.54, 1.42)

RR, rural hukou and rural school group; RU, rural hukou and urban school group; UU, urban hukou and urban school group.

[1] Adjusted for sociodemographic characteristics (i.e., age, sex, parental education level, and gross family income) and individual behaviors (screen time, night sleep duration, and physical activity).

*P <0.05, **P<0.01, ***P <0.001.

The bold words represent the P values less than 0.05.

Table 3 Simple effects of mental health symptoms on executive dysfunction stratified by urban-rural subgroup[1]

	Executive dysfunction		
	OR (95% CI)	*z* value	P value
UU group			
Depression, score ≥ 14	6.74 (3.75, 12.12)	6.38	**< 0.001**
Anxiety, score ≥ 10	5.56 (1.86, 16.66)	3.06	**0.002**
Stress, score ≥ 19	3.14 (1.75, 5.61)	3.85	**< 0.001**
RU group			
Depression, score ≥ 14	4.89 (1.67, 14.25)	2.90	**0.004**
Anxiety, score ≥ 10	3.46 (1.21, 9.84)	2.32	**0.020**
Stress, score ≥ 19	1.65 (0.92, 2.93)	1.69	0.091
RR group			
Depression, score ≥ 14	1.93 (0.91, 4.12)	1.70	0.088
Anxiety, score ≥ 10	1.80 (1.39, 2.33)	4.44	**< 0.001**
Stress, score ≥ 19	1.59 (1.12, 2.27)	2.57	**0.010**

RR, rural hukou and rural school group; RU, rural hukou and urban school group; UU, urban hukou and urban school group.

[1] Adjusted for sociodemographic characteristics (i.e., age, sex, parental education level, and gross family income) and individual behaviors (screen time, night sleep duration, and physical activity).

The bold words represent the P values less than 0.05.

Discussion

To our knowledge, this is the first study to investigate the moderating effect of urban-rural subpopulation on the association between mental health and EDF among general adolescents. We found that mental health symptoms were common in our sample, and their prevalence rates in the RR and RU subgroups were significantly higher than those in the UU subgroup, mainly due to having more screen time. Furthermore, we observed that mental health symptoms were significantly associated with EDF across all subgroups. Moreover, there were also marginal interactive effects of urban-rural subgroup with depression and anxiety on EDF, specifically the UU adolescents with depression and anxiety issues had a much higher EDF risk than their RR peers.

Mental health symptoms were common in our sample, i.e., 25.4%, 52.8% and 19.6% for depression, anxiety, and stress, respectively, which appear to be higher than rates among Hong Kong adolescents (19.1%, 22.9%, and 14.3%).[27] Meanwhile, the mean score of the depression dimension in our dataset (8.5) was higher than that reported among adolescents in Spain (6.0),[28] about the same as that of a study conducted in Australia (8.4),[29] but less than scores reported in America (10.4).[30] The mean anxiety score (10.8) was also higher than that of a study conducted in Australia (7.0).[29]

Our finding that RR and RU adolescents had worse mental health symptoms than their UU peers was in line with prior studies conducted in China[31] and in other countries (e.g., Korea[32] and Australia[33]). Certain behavioral and sociodemographic differences between the urban-rural subgroups explained most of the disparities, which corresponded with the results of a previous study.[34] For example, our study indicated that the significant urban-rural differences of adolescent mental health problems were mainly attributed to screen time, which previous researches have linked it to less face-to-face communication with peers and families, less outdoor physical activity, and

receiving plenty of potentially inappropriate information.[35] Another possible reason for these differences may be that the lower parental education levels and family income among rural adolescents lead to less mental health support.[36] On all accounts, the large share of rural adolescents experiencing more mental health problems is concerning and should receive more attention from policymakers in future adolescent health actions, such as establishing adolescent mental health and hygiene infirmary, and strengthening the publicity and education of the adolescent mental health knowledge in school and community, as well as mobilizing adolescents' enthusiasm of participating in outdoor activities to reduce their media exposure time, because the government policies have the potential to change many of these determinants.

Across all three subgroups in our sample, mental health symptoms were consistently associated with EDF. That is, poor mental health associated with EF impairment even among general adolescents, supporting one recent study with nonclinical-based samples.[10] Studies from clinical patients indicated that the potential mechanism may be attributed to the dysregulation of the hypothalamic–pituitary axis with hyper activity[37] and neural-immune crosstalk with elevated cytokine production[38]. When these occurred in the central nervous system, brain architecture, morphology, and functional activity may be altered, thereby reducing an adolescent's EF.[2 39] More studies on the mechanisms behind the association between mental health and EF in general adolescents should be conducted in the future.

Although we only found a marginal interactive effect of urban-rural subgroup with depression and anxiety, we observed that among adolescents with depression and anxiety symptoms, the UU adolescents had a much higher EDF risk than RR counterparts. While urban regions offer a higher standard of living and a higher quality of healthcare and educational resources than rural areas, stressors in urban

environments, such as high population density, noise pollution, and air pollution, in addition to less access to green spaces and relatively low neighbor communication and support,[17 18 40 41] might strengthen the relationship between mental health problems and EDF, which is also an important topic in need of further empirical study. To improve adolescent mental health and EF, we suggest that the government, school and community should pay much more attention to both investment in mental health support services in rural areas as well as improving the quality of the living environment in urban areas.

The present study has several limitations. Firstly, our data was collected from one relatively low socioeconomic development city in China, and the findings might not be generalizable to the national population. Future samples in other settings with different levels of socioeconomic development should be collected. Secondly, we utilized sub-clinical cutoffs of EDF. Although the effect estimated was at magnitudes that may be considered sub-clinical in adolescents, these findings are important at the population level. Thirdly, our measures of lifestyle behaviors were based on self-report, which may be subject to recall bias. Future studies should collect these data using more objective measurements, such as using actiwatch to assess night sleep duration and physical activity. Fourthly, we did not collect the parenting and caregiving style which might influence the association between mental health and executive dysfunction. Finally, as this is a cross-sectional study, we cannot make causal claims and cannot exclude the possibility that the results may be influenced by residual and unmeasured or unknown factors.

Conclusion

The prevalence of mental health symptoms was significantly higher among rural origin adolescents when compared to their urban peers, and such disparities were primarily

explained by excessive screen exposure. Adolescents with mental health symptoms were more likely to have EDF regardless of urban-rural, and urban adolescents with depression and anxiety had a much higher EDF risk than their rural peers. The results indicate the need to improve mental health issues prevention and treatment in both urban and rural areas, where adolescents may be exposed to different kinds of risk factors that may exacerbate the impact of mental health problems on their EF in daily life.

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Contributors

Qingmin Lin conceptualized and designed the study, carried out the literature review and data analyses, and critically reviewed and revised the manuscript. Cody Abbey carried out the literature review and drafted the initial manuscript. Yunting Zhang, Guanghai Wang, Jinkui Lu, Sarah-Eve Dill, Qi Jiang, Manpreet Kaur Singh, Xinshu She, Huan Wang, and Scott Rozelle critically reviewed and revised the manuscript. Fan Jiang conceptualized and designed the study, as well as critically reviewed and revised the manuscript. All authors read and approved the final manuscript.

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Conflict of interest

The authors declared no conflicts of interest.

Patient consent for publication

Not applicable.

Ethics approval

The study was approved by the Shanghai Children's Medical Center Human Ethics Committee (SCMCIRB-K2018103).

Provenance and peer review

Not commissioned; externally peer reviewed

Data availability statement

Data used for this study were derived from the SCHEDULE-A project. The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

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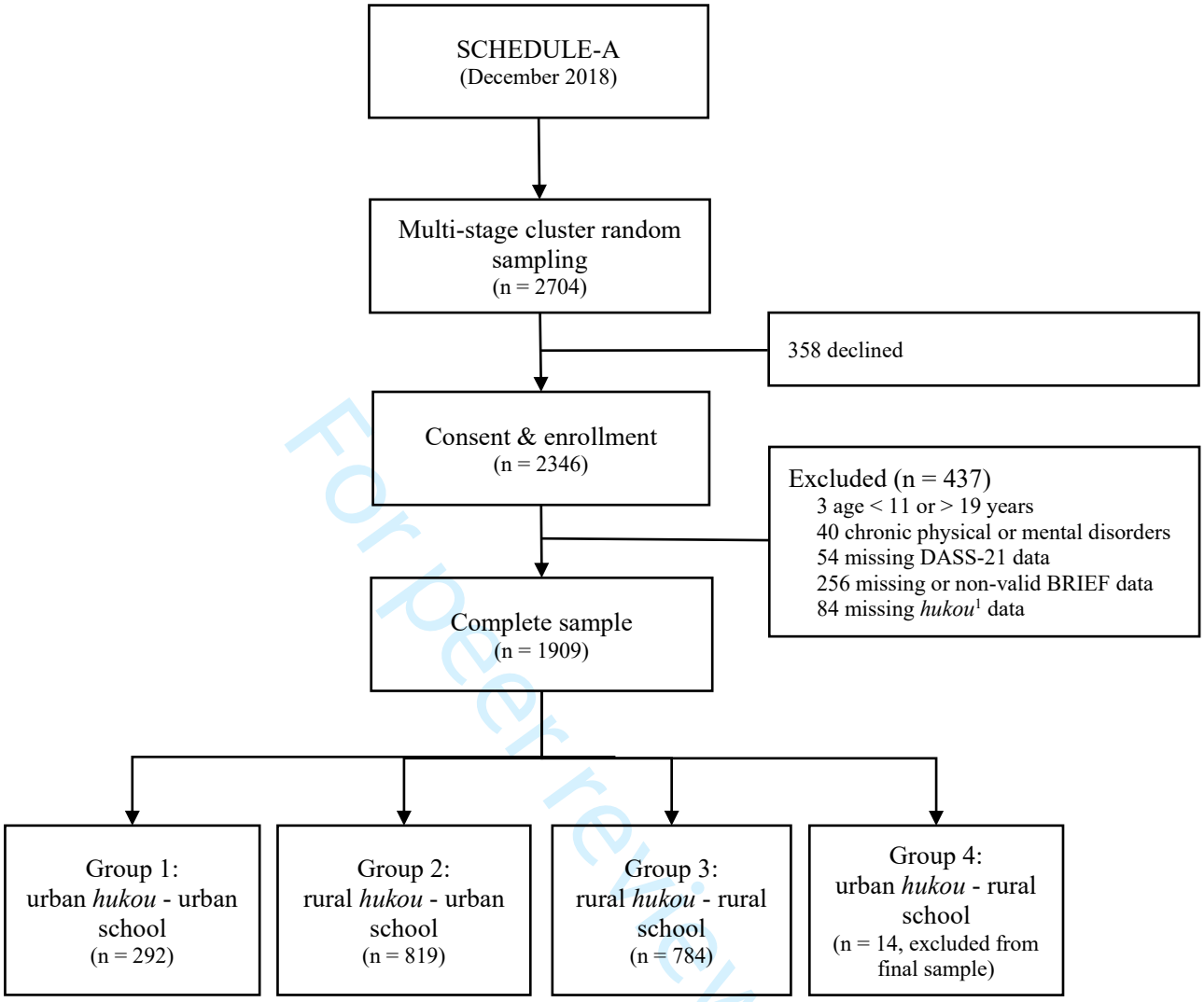

Figure 1 Flowchart of the participants

BRIEF, the Behavior Rating Inventory of Executive Function; DASS-21, the Depression Anxiety and Stress Scale-21; SCHEDULE-A, the Study of the Shanghai Children's Health, Education and Lifestyle Evaluation-Adolescents.

[1] Household registration system in China that was established officially in 1958, based on it each Chinese citizen can be classified into urban or rural origin according to his/her permanent residential area.

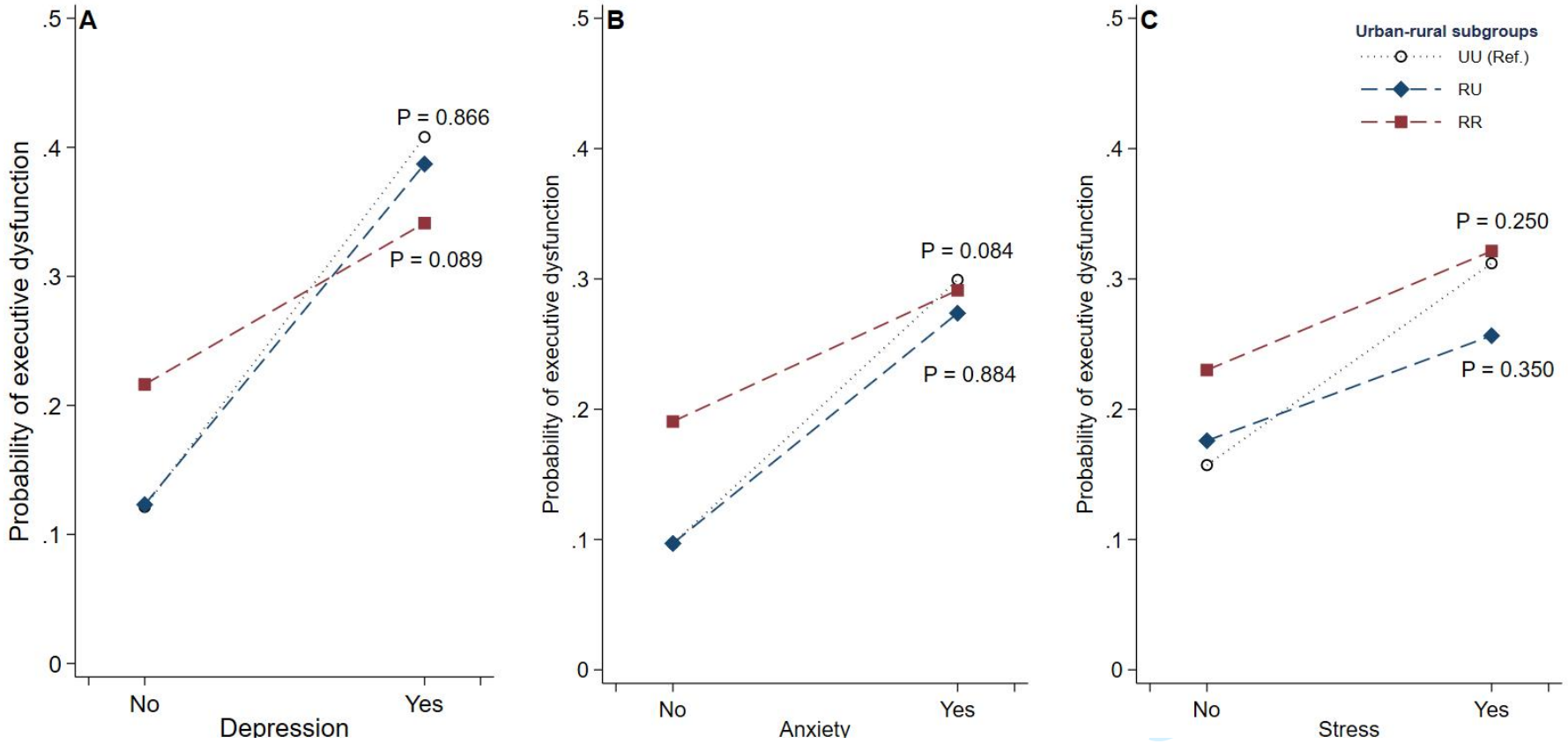

Figure 2 Interactive effects of urban-rural subgroup and mental health symptoms on executive dysfunction

RR, rural hukou and rural school group; RU, rural hukou and urban school group; UU, urban hukou and urban school group.

All models were adjusted for sociodemographic characteristics (i.e., age, sex, parental education level, and gross family income) and individual behaviors (screen time, night sleep duration, and physical activity).

The P values indicated whether each interactive effect of urban-rural subgroups and mental health symptoms on executive dysfunction reached statistical significance.

Table S1 Risk factors for mental health symptoms and executive dysfunction

	Depression		Anxiety		Stress		Executive dysfunction	
	Unadjusted	Adjusted [1]	Unadjusted	Adjusted [1]	Unadjusted	Adjusted [1]	Unadjusted	Adjusted [1]
Urban-rural subgroup								
UU	Ref.	Ref.	Ref.	Ref.	Ref.	Ref.	Ref.	Ref.
RU	1.32 (0.95, 1.83)	1.10 (0.61, 1.98)	**1.56 (1.19, 2.05)****	1.32 (0.85, 2.05)	**1.54 (1.06, 2.22)***	1.46 (0.76, 2.80)	1.09 (0.77, 1.53)	0.77 (0.51, 1.16)
RR	**1.48 (1.07, 2.05)***	1.02 (0.59, 1.77)	**2.00 (1.52, 2.63)*****	1.35 (0.77, 2.39)	**1.57 (1.09, 2.28)***	1.41 (0.95, 2.10)	1.35 (0.96, 1.90)	0.81 (0.35, 1.84)
Sociodemographics								
Age, y	/	0.99 (0.93, 1.05)	/	0.99 (0.93, 1.05)	/	0.99 (0.95, 1.03)	/	0.94 (0.82, 1.10)
Sex, female	/	**1.06 (1.02, 1.10)****	/	**1.39 (1.16, 1.66)*****	/	**1.15 (1.01, 1.32)***	/	0.97 (0.77, 1.21)
Parental education, high school or higher	/	1.14 (0.83, 1.56)	/	**0.82 (0.68, 0.98)***	/	1.26 (1.00, 1.58)	/	**0.68 (0.55, 0.84)*****
Family income, ≥ 50,000 RMB	/	0.87 (0.68, 1.10)	/	**0.85 (0.73, 0.99)***	/	0.97 (0.77, 1.22)	/	**0.61 (0.39, 0.97)***
Individual behaviors								
Screen time								
Passive screen time, ≥ 2h	/	**1.60 (1.22, 2.11)****	/	1.24 (0.81, 1.91)	/	1.23 (0.99, 1.53)	/	1.17 (0.76, 1.78)
Interactive screen time, ≥ 2h	/	**1.20 (1.05, 1.37)****	/	**1.89 (1.41, 2.54)*****	/	**1.36 (1.13, 1.64)****	/	**1.45 (1.29, 1.62)*****
Night sleep duration, short	/	0.93 (0.84, 1.02)	/	1.19 (0.98, 1.45)	/	1.13 (0.79, 1.62)	/	**0.74 (0.58, 0.96)***
Physical activity								
Low	/	Ref.	/	Ref.	/	Ref.	/	Ref.
Moderate	/	0.73 (0.38, 1.39)	/	**0.78 (0.68, 0.90)****	/	**0.64 (0.45, 0.92)***	/	0.80 (0.55, 1.18)
High	/	**0.84 (0.71, 0.98)***	/	0.74 (0.51, 1.09)	/	**0.69 (0.56, 0.84)*****	/	0.85 (0.54, 1.34)

RR, rural hukou and rural school group; RU, rural hukou and urban school group; UU, urban hukou and urban school group.

[1] Adjusted for sociodemographic characteristics (i.e., age, sex, parental education level, and gross family income) and individual behaviors (screen time, night sleep duration, and physical activity).

*P <0.05, **P <0.01, ***P <0.001.

The bold words represent the P values less than 0.05.

Table S2 Adjusting risk factors step by step for mental health symptoms

	Depression		Anxiety		Stress	
	OR (95% CI)	R^2	OR (95% CI)	R^2	OR (95% CI)	R^2
Model 1		0.003		0.010		0.004
Urban-rural subgroup						
UU	Ref.		Ref.		Ref.	
RU	1.32 (0.95, 1.83)		**1.56 (1.19, 2.05)****		**1.54 (1.06, 2.22)***	
RR	**1.48 (1.07, 2.05)***		**2.00 (1.52, 2.63)*****		**1.57 (1.09, 2.28)***	
Model 2		0.004		0.010		0.004
Urban-rural subgroup						
UU	Ref.		Ref.		Ref.	
RU	1.32 (0.95, 1.83)		**1.56 (1.19, 2.05)****		**1.54 (1.06, 2.22)***	
RR	**1.45 (1.04, 2.01)***		**1.98 (1.51, 2.61)*****		**1.55 (1.07, 2.24)***	
Age, y	0.96 (0.90, 1.01)		0.98 (0.93, 1.03)		0.97 (0.90, 1.03)	
Model 3		0.003		0.013		0.004
Urban-rural subgroups						
UU	Ref.		Ref.		Ref.	
RU	1.32 (0.95, 1.83)		**1.57 (1.20, 2.05)****		**1.54 (1.06, 2.22)***	
RR	**1.48 (1.07, 2.05)***		**2.00 (1.52, 2.63)*****		**1.57 (1.09, 2.27)***	
Sex, female	1.02 (0.83, 1.26)		**1.32 (1.10, 1.58)****		1.13 (0.90, 1.42)	
Model 4		0.003		0.012		0.004
Urban-rural subgroup						
UU	Ref.		Ref.		Ref.	
RU	1.32 (0.94, 1.84)		**1.44 (1.08, 1.91)***		**1.6 (1.09, 2.34)***	
RR	**1.45 (1.03, 2.04)***		**1.81 (1.36, 2.42)*****		**1.65 (1.12, 2.43)***	
Parental education, high school or higher	0.98 (0.77, 1.26)		**0.78 (0.63, 0.97)***		1.11 (0.85, 1.46)	
Model 5		0.003		0.012		0.003
Urban-rural subgroup						
UU	Ref.		Ref.		Ref.	
RU	1.20 (0.85, 1.71)		**1.58 (1.17, 2.12)****		1.45 (0.97, 2.16)	
RR	1.38 (0.96, 1.97)		**1.93 (1.42, 2.62)*****		**1.54 (1.02, 2.31)***	
Family income, ≥ 50,000 RMB	0.86 (0.68, 1.10)		**0.80 (0.65, 0.99)***		1.00 (0.77, 1.30)	
Model 6		**0.018**		**0.024**		**0.011**
Urban-rural subgroup						
UU	Ref.		Ref.		Ref.	
RU	1.15 (0.83, 1.60)		**1.37 (1.04, 1.81)***		1.39 (0.96, 2.01)	
RR	1.16 (0.82, 1.63)		**1.54 (1.16, 2.05)****		1.29 (0.88, 1.90)	
Passive screen time, ≥ 2h	**1.71 (1.36, 2.15)*****		**1.39 (1.14, 1.70)****		**1.34 (1.05, 1.71)***	
Interactive screen time, ≥ 2h	1.20 (0.95, 1.51)		**1.51 (1.23, 1.87)*****		**1.30 (1.01, 1.67)***	
Model 7		0.003		0.011		0.004
Urban-rural subgroup						
UU						
RU	1.31 (0.94, 1.81)		**1.57 (1.20, 2.06)****		**1.55 (1.07, 2.25)***	
RR	**1.40 (1.00, 1.96)***		**2.09 (1.58, 2.76)*****		**1.66 (1.14, 2.42)****	
Sleep duration, short	0.91 (0.74, 1.14)		1.15 (0.95, 1.39)		1.12 (0.89, 1.42)	
Model 8		0.006		0.011		0.009
Urban-rural subgroup						
UU	Ref.		Ref.		Ref.	
RU	1.29 (0.93, 1.79)		**1.56 (1.19, 2.05)****		**1.53 (1.06, 2.21)***	
RR	**1.42 (1.03, 1.98)***		**1.98 (1.50, 2.60)*****		**1.54 (1.07, 2.23)***	
Physical activity						
Low	Ref.		Ref.		Ref.	
Moderate	**0.75 (0.57, 0.97)***		0.81 (0.65, 1.02)		**0.63 (0.48, 0.83)****	
High	1.00 (0.77, 1.29)		0.85 (0.68, 1.07)		**0.75 (0.57, 0.99)***	
Model 9		0.015		**0.031**		0.008
Urban-rural subgroup						
UU	Ref.		Ref.		Ref.	
RU	1.11 (0.77, 1.59)		1.29 (0.95, 1.77)		1.43 (0.95, 2.14)	
RR	1.11 (0.75, 1.63)		1.32 (0.94, 1.84)		1.38 (0.90, 2.14)	
Parental education, high school or higher	1.13 (0.85, 1.49)		0.82 (0.64, 1.05)		1.23 (0.91, 1.66)	
Family income, ≥ 50,000 RMB	0.84 (0.66, 1.08)		0.83 (0.67, 1.03)		0.95 (0.73, 1.25)	
Passive screen time, ≥ 2h	**1.57 (1.22, 2.03)****		1.21 (0.96, 1.52)		1.20 (0.91, 1.57)	
Interactive screen time, ≥ 2h	1.21 (0.93, 1.57)		**1.79 (1.42, 2.27)*****		1.27 (0.95, 1.69)	

RR, rural hukou and rural school group; RU, rural hukou and urban school group; UU, urban hukou and urban school group.
*P <0.05, **P <0.01, ***P <0.001.
The bold words represent the P values less than 0.05.

Table S3 Interactive effects of urban-rural subgroup and mental health symptoms on executive dysfunction

	Executive dysfunction			
	Unadjusted		Adjusted	
	OR (95% CI)	P value	OR (95% CI)	P value
Model a				
Depression	4.64 (2.43, 8.85)	**< 0.001**	5.31 (2.01, 14.02)	**0.001**
RU	0.96 (0.61, 1.50)	0.845	0.73 (0.46, 1.15)	0.171
RR	1.69 (1.09, 2.61)	**0.018**	1.12 (0.36, 3.46)	0.848
RU*Depression	1.10 (0.52, 2.32)	0.797	0.89 (0.23, 3.50)	0.866
RR*Depression	0.42 (0.20, 0.87)	**0.020**	0.36 (0.11, 1.17)	0.089
Model b				
Anxiety	3.67 (1.96, 6.85)	**< 0.001**	4.13 (1.29, 13.3)	**0.017**
RU	0.95 (0.52, 1.70)	0.852	0.73 (0.27, 2.00)	0.546
RR	1.65 (0.94, 2.93)	0.083	1.26 (0.43, 3.68)	0.673
RU*Anxiety	1.00 (0.48, 2.09)	0.997	0.88 (0.15, 5.26)	0.884
RR*Anxiety	0.57 (0.28, 1.16)	0.122	0.43 (0.16, 1.12)	0.084
Model c				
Stress	2.29 (1.10, 4.77)	**0.028**	2.52 (0.96, 6.61)	0.061
RU	1.11 (0.75, 1.63)	0.615	0.80 (0.43, 1.49)	0.489
RR	1.38 (0.94, 2.03)	0.103	0.85 (0.35, 2.07)	0.723
RU*Stress	0.76 (0.33, 1.75)	0.521	0.65 (0.27, 1.60)	0.350
RR*Stress	0.75 (0.33, 1.72)	0.498	0.64 (0.30, 1.37)	0.250

RR, rural hukou and rural school group; RU, rural hukou and urban school group.

[1] All models were adjusted for sociodemographic characteristics (i.e., age, sex, parental education level, and gross family income) and individual behaviors (screen time, night sleep duration, and physical activity).

The bold words represent the P values less than 0.05.

Table S4 Simple effects of urban-rural subgroups on executive dysfunction stratified by mental health symptoms[1]

	Executive dysfunction		
	OR (95% CI)	*z* value	P value
Depression state			
No depression			
Urban-rural subgroup			
UU	Ref.		
RU	0.73 (0.41, 1.29)	-1.09	0.277
RR	1.02 (0.35, 2.93)	0.03	0.975
Depression			
Urban-rural subgroup			
UU	Ref.		
RU	0.58 (0.23, 1.52)	-1.10	0.270
RR	0.40 (0.21, 0.75)	-2.84	**0.004**
Anxiety state			
No anxiety			
Urban-rural subgroup			
UU	Ref.		
RU	0.78 (0.29, 2.13)	-0.48	0.631
RR	1.55 (0.53, 4.48)	0.80	0.422
Anxiety			
Urban-rural subgroup			
UU	Ref.		
RU	0.61 (0.26, 1.46)	-1.11	0.269
RR	0.49 (0.22, 1.08)	-1.76	0.078
Stress state			
No stress			
Urban-rural subgroup			
UU			
RU	0.82 (0.41, 1.65)	-0.55	0.585
RR	0.84 (0.29, 2.39)	-0.33	0.742
Stress			
Urban-rural subgroup			
UU	Ref.		
RU	0.44 (0.16, 1.21)	-1.59	0.112
RR	0.57 (0.20, 1.59)	-1.08	0.281

RR, rural hukou and rural school group; RU, rural hukou and urban school group; UU, urban hukou and urban school group.

[1] All models were adjusted for sociodemographic characteristics (i.e., age, sex, parental education level, and gross family income) and individual behaviors (screen time, night sleep duration, and physical activity).

The bold words represent the P values less than 0.05.

Table S5 Interactive effects of urban-rural subgroups and mental health symptoms on executive dysfunction (imputed data)

	Executive dysfunction			
	Unadjusted		Adjusted	
	OR (95% CI)	P value	OR (95% CI)	P value
Model a				
Depression	4.64 (2.43, 8.85)	**< 0.001**	5.20 (1.89, 14.27)	**0.001**
RU	0.96 (0.61, 1.50)	0.845	0.72 (0.54, 0.95)	**0.021**
RR	1.69 (1.09, 2.61)	**0.018**	0.98 (0.39, 2.46)	0.969
RU*Depression	1.10 (0.52, 2.32)	0.797	0.88 (0.27, 2.87)	0.828
RR*Depression	0.42 (0.20, 0.87)	**0.020**	0.37 (0.11, 1.21)	0.101
Model b				
Anxiety	3.67 (1.96, 6.85)	**< 0.001**	3.64 (1.29, 10.22)	**0.014**
RU	0.95 (0.52, 1.70)	0.852	0.71 (0.32, 1.58)	0.403
RR	1.65 (0.94, 2.93)	0.083	0.97 (0.38, 2.48)	0.947
RU*Anxiety	1.00 (0.48, 2.09)	0.997	0.94 (0.18, 4.96)	0.939
RR*Anxiety	0.57 (0.28, 1.16)	0.122	0.55 (0.24, 1.27)	0.162
Model c				
Stress	2.29 (1.10, 4.77)	**0.028**	2.35 (0.83, 6.66)	0.107
RU	1.11 (0.75, 1.63)	0.615	0.78 (0.47, 1.31)	0.348
RR	1.38 (0.94, 2.03)	0.103	0.75 (0.37, 1.54)	0.438
RU*Stress	0.76 (0.33, 1.75)	0.521	0.71 (0.22, 2.31)	0.566
RR*Stress	0.75 (0.33, 1.72)	0.498	0.71 (0.30, 1.71)	0.449

RR, rural hukou and rural school group; RU, rural hukou and urban school group.

[1] All models were adjusted for sociodemographic characteristics (i.e., age, sex, parental education level, and gross family income) and individual behaviors (screen time, night sleep duration, and physical activity).

The bold words represent the P values less than 0.05.

Table S6 Simple effects of mental health symptoms on executive dysfunction stratified by urban-rural subgroup1 (imputed data)

	Executive dysfunction		
	OR (95% CI)	*z* value	P value
UU group			
Depression, score ≥ 14	6.21 (3.37, 11.45)	5.86	**< 0.001**
Anxiety, score ≥ 10	4.69 (1.71, 12.85)	3.00	**0.003**
Stress, score ≥ 19	2.98 (1.65, 5.40)	3.61	**< 0.001**
RU group			
Depression, score ≥ 14	4.78 (1.95, 11.72)	3.42	**0.001**
Anxiety, score ≥ 10	3.33 (1.33, 8.34)	2.56	**0.010**
Stress, score ≥ 19	1.67 (0.84, 3.33)	1.46	0.143
RR group			
Depression, score ≥ 14	1.91 (0.92, 3.96)	1.75	0.080
Anxiety, score ≥ 10	2.04 (1.39, 2.98)	3.67	**< 0.001**
Stress, score ≥ 19	1.68 (1.23, 2.31)	3.23	**0.001**

RR, rural hukou and rural school group; RU, rural hukou and urban school group; UU, urban hukou and urban school group.

[1] Adjusted for sociodemographic characteristics (i.e., age, sex, parental education level, and gross family income) and individual behaviors (screen time, night sleep duration, and physical activity).

The bold words represent the P values less than 0.05.

Table S7 Simple effects of urban-rural subgroups on executive dysfunction stratified by mental health symptoms1 (imputed data)

	Executive dysfunction		
	OR (95% CI)	*z* value	P value
Depression state			
No depression			
Urban-rural subgroup			
UU	Ref.		
RU	0.72 (0.51, 1.01)	-1.88	0.060
RR	0.90 (0.39, 2.08)	-0.25	0.801
Depression			
Urban-rural subgroup			
UU	Ref.		
RU	0.61 (0.29, 1.28)	-1.31	0.191
RR	0.39 (0.23, 0.68)	-3.36	**0.001**
Anxiety state			
No anxiety			
Urban-rural subgroup			
UU	Ref.		
RU	0.76 (0.32, 1.8)	-0.62	0.538
RR	1.08 (0.40, 2.95)	0.15	0.878
Anxiety			
Urban-rural subgroup			
UU	Ref.		
RU	0.64 (0.25, 1.62)	-0.95	0.344
RR	0.50 (0.30, 0.86)	-2.54	**0.011**
Stress state			
No stress			
Urban-rural subgroup			
UU	Ref.		
RU	0.79 (0.44, 1.41)	-0.81	0.419
RR	0.72 (0.30, 1.73)	-0.73	0.463
Stress			
Urban-rural subgroup			
UU	Ref.		
RU	0.51 (0.16, 1.66)	-1.12	0.265
RR	0.61 (0.23, 1.62)	-0.99	0.323

RR, rural hukou and rural school group; RU, rural hukou and urban school group; UU, urban hukou and urban school group.

[1] All models were adjusted for sociodemographic characteristics (i.e., age, sex, parental education level, and gross family income) and individual behaviors (screen time, night sleep duration, and physical activity).

The bold words represent the P values less than 0.05.

STROBE Statement—Checklist of items that should be included in reports of ***cross-sectional studies***

	Item No	Recommendation	Page No
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract	2,4
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found	4-5
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	7-9
Objectives	3	State specific objectives, including any prespecified hypotheses	9
Methods			
Study design	4	Present key elements of study design early in the paper	9
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	9
Participants	6	(*a*) Give the eligibility criteria, and the sources and methods of selection of participants	9
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	10-12
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	10-12
Bias	9	Describe any efforts to address potential sources of bias	12
Study size	10	Explain how the study size was arrived at	Figure 1
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	10-12
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding	12
		(*b*) Describe any methods used to examine subgroups and interactions	12
		(*c*) Explain how missing data were addressed	12
		(*d*) If applicable, describe analytical methods taking account of sampling strategy	12
		(*e*) Describe any sensitivity analyses	12
Results			
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	Figure 1
		(b) Give reasons for non-participation at each stage	Figure 1
		(c) Consider use of a flow diagram	Figure 1
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	14, Table 1
		(b) Indicate number of participants with missing data for each variable of interest	Figure 1

Outcome data	15*	Report numbers of outcome events or summary measures	Table 1
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	14-15, Table 2-3, S1-S7
		(*b*) Report category boundaries when continuous variables were categorized	Table 1-3,S1-S2, S6
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	Not applicable
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	15
Discussion			
Key results	18	Summarise key results with reference to study objectives	18
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	20
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	20-21
Generalisability	21	Discuss the generalisability (external validity) of the study results	20-21
Other information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	21-22

*Give information separately for exposed and unexposed groups.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.